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SHARING BETWEEN THE BROADCAST SERVICE AND VHF RADIO RT-F200 IN FREQUENCY HOPPING MODE

by

Graeme G. Glenn
Communications Engineering Unit

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ABSTRACT

Several reports on interference caused by Frequency Hopping radios are reviewed. A theoretical model based on ITU-R IS.851-1 is developed and validated against data obtained from measurements made at Department of Communications and the Arts Laboratories. Parameters for various antenna configurations used in the Australian Army are then given and coupled with pathloss predictions to estimate required distance separations for full band frequency hopping radios from Primary Service areas of Television Broadcast transmitters.

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EXECUTIVE SUMMARY

In the 1970's the Australian Army commenced a replacement program to replace its fleet of radio equipment with a modern Frequency Hopping radio system. The main advantages were seen to be in Electronic Warfare and little consideration was given to use in Peace Time. With the impending introduction of Frequency Hopping radios in both the USA and Australia the implications of Frequency Hopping on other services needed to be considered.

In the US the FCC made a number of restrictive rulings. As a consequence two reports were commissioned which show that the FCC rulings are overly conservative. The first shows that ground based Frequency Hopping operation can be conducted with an exclusion zone of 18.5 kms around a class B area. A second report indicates that the exclusion zone may be as low as 2.9 kms. The reports also show that environmental noise, television antenna gain, directivity and cross polarisation characteristics need to be taken into account when determining required Protection Ratios for Frequency Hopping radios.

In the mean time the ITU made recommendations about frequency sharing with Television Broadcast stations. However their recommendations are based solely on fixed frequency operation and do not take into account frequency agile systems. The ITU recommendations are applied to Australian conditions and the ITU recommendations for Fixed Frequency Tropospheric propagation is presented in the report.

In Australia a report on measurements made by the Department of Communications and the Arts (DOCA) made several recommendations about required Protection Ratios and exclusion zones for Australian conditions. These recommendations were based on both measured data and assumptions made about the operation of Frequency Hopping radios within Army. Subsequent data has shown that some of these assumptions were incorrect.

A theoretical model is developed which indicates that the interference mechanism is based on Average Power rather than Peak Power. As a consequence 2nd harmonic emissions of Frequency Hopping radios do not have the influence indicated in the DOCA report and are an insignificant factor in the interference caused to Television.

Antennas in use within Army are described and their parameters used with ITU Pathloss calculations to determine how far outside the Primary Service area Frequency Hopping radios need to be before unrestricted operation can be permitted. For Manpack operation this can be as low as 1 km. If the TV Channel itself is excluded all current configurations can operate from 1 km outside the Primary Service area.

THE AUTHOR

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has both a Diploma in Electronic Engineering and a Bachelor of Engineering in Communications. His career spans 20 years in electronic systems, testing, evaluation and software. He managed the installation and design of communications systems for the RAN before becoming the Principal Technical Advisor for VHF Systems at ATEA where he has been responsible for specification, evaluation, and design approval testing of the RAVEN VHF Radio and Sub-System. Seconded to the UK for 3 years, he worked as the Commonwealth's representative on the VHF Design Team developing software and hardware for the system. Since his return to ATEA he has been responsible for the oversight of production and enhancements to the software as well as giving oversight to a number of other projects

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1. Technical Note, CEU/TNV/0121, Sharing between Receiver/Transmitter RT-F200 and VHF Broadcast Services, dated 10 September 96.

2. Technical Note, CEU/TNV/0123, ITU Protection Ratios for Australian Television Channels sharing with Fixed and Mobile stations causing Tropospheric or equivalent interference in the 30 to 88 MHz band, 15 September 96.

3. Technical Note, CEU/TNV/0124, Theoretical Analysis of CCIR Protection Ratios for Australian Television Channels for the RAVEN VHF Frequency Hopping Modulation Scheme

4. Technical Note, CEU/TNV/0128, ITU Protection Ratios for USA NTSC Television Channels sharing with Fixed and Mobile stations causing continuous or equivalent interference in the 30 to 88 MHz band, 15 October 96.

SHARING BETWEEN THE BROADCAST SERVICE AND VHF RADIO RT-F200 IN FREQUENCY HOPPING MODE

REFERENCES

A. MITRE WORKING PAPER, WP-91W00228, Single Channel Ground Airborne Radio System (SINCGARS)/Television Interference (TVI) Test Report, J.L. Klenk, L.L. Taylor, July 1991.

B. TEST REPORT, EMETF-92-03-008, Television Interference Test of the Single Channel Ground Airborne Radio System (SINCGARS), James Billingsley, May 1992.

C. Recommendation ITU-R IS.851-1, Sharing between the Broadcasting Service and the Fixed and/or Mobile Services in the VHF and UHF Bands, 1992-1993

D. Department of Communications and the Arts Laboratory Report No. 94-9, Defence Department Raven Radio Investigations, Maurie Daly, 18 April 94.

E. Technical Note, CEU/TNV/0123, ITU Protection Ratios for Australian Television Channels sharing with Fixed and Mobile stations causing Tropospheric or equivalent interference in the 30 to 88 MHz band, 15 September 96.

F. Technical Note, CEU/TNV/0128, ITU Protection Ratios for USA NTSC Television Channels sharing with Fixed and Mobile stations causing continuous or equivalent interference in the 30 to 88 MHz band, 15 October 96.

INTRODUCTION

1. In the 1970's the Australian Army commenced its search for a replacement radio for the ageing fleet of radios held by the Australian Army. Proposals for the new fleet of radios included two novel ideas. One of those ideas was to achieve interoperability between HF and VHF spectrum radios enabling: the radios to communicate with each other and rebroadcast each others data and messages through a common data bus, and to use a suite of common ancillaries. The other novel idea, which had never been implemented in a production radio before, was to have both VHF and HF radios which were frequency agile or capable of frequency hopping.

2. It is the spectrum management of VHF Frequency Hopping radios with which this paper deals.

ELECTRONIC WARFARE AND FREQUENCY HOPPING

3. In the 1970's when military forces around the world were considering the introduction of Frequency Hopping radios, the prime interest was the Electronic Warfare (EW) benefits that such radios would offer. These benefits included making signals far harder to intercept and even harder to Jam. As with all systems, there are some advantages and disadvantages. The disadvantage of Frequency Hopping is that Frequency Hopping radios can have an effect on other non-frequency hopping systems and services using the same radio frequency spectrum, even though this may be minimal. The impact of Frequency Hopping on other defence radio systems was considered and

measures were implemented to overcome any possible disadvantages. Very little consideration was given to the impact of Frequency Hopping on other peace time users of the spectrum and peace time spectrum management.

PEACE TIME USE OF FREQUENCY HOPPING

4. As the use of Frequency Hopping radios in the field became imminent, the Defence Departments of both the USA and Australia began to investigate the ramifications of Frequency Hopping on other peace time users. In the USA, sharing provisions were negotiated in 1985 between the US Army with the Federal Communications Commission (FCC) on a non-interference basis. This frequency sharing agreement was based on tests conducted at FCC laboratories. The FCC, however was concerned about the potential for Single Channel Ground Airborne Radio System (SINCGARS) radios to cause television interference and directed in 1991 that Frequency Hopping operation of SINCGARS be confined to below 50 MHz and that authorisation for use above 50 MHz be co-ordinated at the national level. Meanwhile the US Army began investigating the effect of frequency hopping on television and produced a working paper in July 1991, Reference A, and a Test Report in May 1992, Reference B. These reports concluded that the frequency sharing criteria established by the FCC in 1985 were "overly conservative".

ITU AND SPECTRUM REUSE

5. At the same time, due to increasing spectrum congestion, the idea of frequency reuse became more acceptable and the International Telecommunications Union (ITU) has issued a number of recommendations on frequency sharing of the radio spectrum. In particular the ITU has issued recommendation ITU-R IS.851-1, "Sharing between the Broadcasting Service and the Fixed and/or Mobile Services in the VHF and UHF Bands", 1992-1993, Reference C.

AUSTRALIAN TVI TESTING

6. In 1994 with deployment of RAVEN VHF radios imminent, the Australian Army and the Department of Communications and the Arts (DOCA), under the auspices of the Department of Defence, Joint Communications Electronics Branch, Spectrum Management, conducted some testing at the DOCA Communications Laboratory, Reference D. The testing aimed to quantify the effect of Frequency Hopping on television systems in Australia. The author was present at the time of the testing as an observer, to provide advice on the radio, and assistance in setting up required radio operating frequencies.

7. The DOCA report gives guidelines for use of the RAVEN VHF radio in Frequency Hopping mode on a non-interference basis. Further analysis as a result of investigation into the impact of ITU-R IS.851-1 has shown that many of the assumptions made in the report, due to lack of data, need revision. Consequently some of the conclusions, recommendations, and results shown in example scenarios, may be questioned.

BACKGROUND

ITU CONCEPTS

8. ITU recommendation ITU-R IS.851-1 introduces the idea of Protection Ratio which is the ratio of the TV signal level to the interfering signal level and is given in dB. The protection ratio is usually specified as that required to enable interference free TV reception at the limits of TV reception which

in the US is regarded as the contour where signal levels are down to 47 dBuV/m. This is often referred to as the 47 dBuV/m or the Class B Television contour. In Australia the limit for TV reception is regarded as being 50 dBuV/m. The areas inside these contours are the Primary Service areas for the particular Television station in question.

TV CHANNEL CHARACTERISTICS

9. Australia and the US have different TV Channel characteristics. The major differences are that the US TV channels are 6 MHz wide and the modulation standard is NTSC. Australia uses a channel width of 7 MHz and the modulation standard is PAL-D. The technical characterisitics of channels both in Australia and the US are summarised in CEU/TNV/0123 and CEU/TNV/0128. The protection ratio required by the two modulation schemes is different and it appears that the NTSC requires 10 dB more protection as whole than PAL-D.

AIM

10. The aim of this report is to formulate guidelines for operation of VHF Frequency Hopping radios in the vicinity of TV stations within Australia without causing perceptible interference.

METHODOLOGY

11. The methodology undertaken examines the available empirical data obtained from both US and Australian reports and examines the requirements of ITU-R IS.851-1. A theoretical basis which explains and enables the prediction of required protection ratios based on the TV Protection Ratio characteristic contained in ITU recommendations is developed and then verified against measured data. This theoretical basis is then used to explain observed data. Other data is then examined which provides worst case characteristics of antennas used in various Australian Defence applications. ITU recommendations are then used to make range and pathloss predictions and finally predict protection ratios obtained at television receiver sites. Recommendations are then made on the basis of these predictions.

USA DATA

PREVIOUS FCC DECISIONS

12. In the USA the FCC has been concerned about possible interference caused by Frequency Hopping radios, SINCGARS, since 1983. In 1985, tests were conducted by the FCC in co-operation with the US Army, using SINCGARS initial production models, to establish criteria for operation for the USA. The FCC determined that protection criteria for SINCGARS varied from 35 to 40 dB depending on the particular hopset used. The FCC then required that for co-channel operation that the Frequency Hopping radio signal be 50 dB below the received television signal at the Grade B television contour of 47 dBuV/m. This requirement was based in part on a sample of six television receivers measured in FCC laboratories. The FCC requirement for a protection ratio of 50 dB was the same as for single channel land mobile radio telephone transmitters. Based on the 50 dB protection ratio, a separation of 93 kms was required by the FCC between any TV receiver inside the Grade B television area and a Frequency Hopping radio.

13. Subsequently to this the FCC, in October 1991, decided that Frequency Hopping operation could only be conducted unrestricted below 50 MHz. This allows a four MHz guard band between

Frequency Hopping operation and any Television Channel. Frequency Hopping above 50 MHz required national authorisation.

SINCGARS TESTS

14. Earlier that year, 1991, PM SINCGARS commenced preparation for tests which would document the measured relationship between Frequency Hopping radio emissions and received TV signal level whilst monitoring interference level. Two reports were produced as a result of this investigation: a Working Paper produced by Mitre Corporation, Reference A, and a Test Report providing supplemental information produced by US Army Test and Evaluation Command, Reference B.

MITRE CORPORATION WORKING PAPER

15. Mitre Corporation was engaged by PM SINCGARS to perform testing of Television Interference (TVI) caused by Frequency Hopping with SINCGARS radios. The testing was conducted during 1991 with the aid of a Cable Television Company, the advice of the FCC, and assistance of various US Defense organisations.

Test Parameters

16. The testing used a 50 Watt SINCGARS vehicle station, and USA TV channels 2, 4 & 6, covering 54 to 88 MHz, were monitored. The tests were conducted on the boundary of a US Class B television service area, at the 47 dBuV/m or -65 dBm contour. Television station reception was available from remote stations using antennas mounted on 12 to 18 meter masts and from local stations using virtually any antenna. The site was outside the Class B boundary for the remote stations and on the Class B boundary for local stations.

17. The antenna used in testing was a commercial directional home receiver antenna which was calibrated for gain, transmission line and other losses at the frequency of interest. The Hop Sets normally used for operational purposes were not used as it was believed that these hopsets resulted in too infrequent hits for reliable observation of the interference threshold (Reference B, Appendix E).

Hop Sets

18. The hopsets for field testing used 25 kHz channels within the TV station channels, in most cases using all available 25 kHz channels, 240 channels, within the TV station channel. The Hop Sets for laboratory testing used a hopset which consisted of five 25 kHz channels with the following frequencies:

a. one frequency 0.5 MHz below the band edge of each of TV channels 2, 4 and 6; and

b. one frequency 0.5 MHz above the band edge of each of TV channels 2 and 4.

Laboratory Test Data

19. The test data documented in Reference A indicates that the variation in USA TV receiver susceptibility to interference is of the order of 30 dB. Of 27 receivers sampled, laboratory results for 8 receivers are presented in the report. The eight receivers chosen are a cross section of the 27 receivers and comprise the worst performers, best performers and middle ground performers.

20. One point that this survey highlights is the lack of such data for Television receivers manufactured for the Australian market. Without such data it is impossible to estimate the variation in performance that can be expected between Television receivers. It seems necessary therefore that a similar survey of TV receivers in Australia needs to be conducted so as to ascertain the range of response to be expected in TV station service areas.

Measurement Uncertainty

21. The Working Paper presents test data for eight TV receivers. The data includes the TV Signal Generator output on three TV channels for the eight receivers. One problem with the measured data however is the level of uncertainty in the measurement data. The table below, Table 1, shows eight measurements of the TV Signal Generator output power for the three different TV channels. If the inaccuracy in the measurement data is defined as three standard deviations, the error in the data could be as much as +/- 5 dB. If data such as this is collected again far more attention to inaccuracies in the measurement system needs to be taken, or an explanation for the variation in the data should be given. There may be good reason for the variation which has nothing to do with measurement uncertainty.

	TV Video Output Power dBm		
	Channel 2	**Channel 4**	**Channel 6**
	60.7	61.6	61.3
	60.6	60.9	61
	60.9	61	61
	63	63.4	65.1
	63	62.4	64.3
	62.7	62.9	63.5
	63.1	63.7	64.2
	63.3	63.3	64.5
Mean dBm	62.1625	62.4	63.1125
Standard Deviation (SD) dB	1.197542	1.108409	1.724974
3*SD dB	3.592626	3.325228	5.174922

Table 1 Comparision of TV Signal Generator Output

Protection Ratio Improvement

22. Despite the error margins shown above, the laboratory measurements reveal some interesting characteristics about the effect of Frequency Hopping on TV channels when the Protection Ratio data measured for Channels 2 and 4 are compared with Protection Ratio data for Channel 6. The tables below, Table 2 to Table 3, give the data measured for eight of the 27 TV receiver sets on Channels 2, 4 and 6. The Protection Ratio for each TV receiver and Channel is calculated. The last Table, Table 5, compares the Protection Ratios found for Channel 2 and 4 with Channel 6. The minimum improvement in Protection Ratio is 5 dB and the largest improvement is 30 dB.

	Channel 2 data							
SINCGARS dBm	-48.15	-78.45	-80.50	-60	-71.9	-71.85	-70.6	-70.3
TV Signal dBm	-60.7	-60.6	-60.90	-63	-63	-62.7	-63.1	-63.3
Protection Ratio dB	-12.55	17.85	19.6	-3	8.9	9.15	7.5	7

Table 2 USA Channel 2 Protection Ratio Measurements

	Channel 4 data							
SINCGARS dBm	-49.15	-79.55	-75.00	-63.15	-69.65	-70.6	-71.6	-70.6
TV Signal dBm	-61.6	-60.9	-61.00	-63.4	-62.4	-62.9	-63.7	-63.3
Protection Ratio dB	-12.45	18.65	14	-0.25	7.25	7.7	7.9	7.3

Table 3 USA Channel 4 Protection Ratio Measurements

	Channel 6 data							
SINCGARS dBm	-37	-48.7	-57.60	-41.5	-67.3	-54.2	-62.5	-61.7
TV Signal dBm	-61.3	-61	-61.00	-65.1	-64.3	-63.5	-64.2	-64.5
Protection Ratio dB	-24.3	-12.3	-3.4	-23.6	3	-9.3	-1.7	-2.8

Table 4 USA Channel 6 Protection Ratio Measurements

	Change in Protection Ratio Data Channels 2 & 4 v's 6							
Mean Channels 2 & 4 PR dB	-12.5	18.25	16.80	-1.625	8.075	8.425	7.7	7.15
Channel 6 PR dB	-24.3	-12.3	-3.40	-23.6	3	-9.3	-1.7	-2.8
Improvement in dB	-11.8	-30.55	-20.2	-21.975	-5.075	-17.725	-9.4	-9.95

Table 5 Protection Ratio Improvement

23. One problem with the Working Paper is the large variation in the Protection Ratio for various TV sets. The large variation in the change in Protection Ratio suggests that there may be errors in the test method and data collection process which have not been accounted for. Despite this reservation, it is obvious that the there is a significant reduction in the interference caused to Channel 6 compared with other Channels, which corresponds to the reduced number of frequency hops in the vicinity of Channel 6 compared with other channels. Understanding the interference mechanism should provide some light on how to interpret test data and predict performance.

Field Data

24. Field data was collected by using a recreation vehicle, TV Observation vehicle (TVO), fitted with victim TV receivers which spanned the range of performance of the 27 sampled TV receivers used in the laboratory. Another vehicle was fitted with a SINCGARS 50 Watt station as the transmit vehicle. The TVO sites were elevated above the general terrain. Hopsets were selected to cause the most interference, by hopping on frequencies only within the Television Channel being monitored.

25. The transmit vehicle was moved to a variety of locations always in the main lobe of the receiving antenna and between the TV transmitter and TVO. Each TV channel was monitored for interference during transmission with data being recorded on video tape. The data collected shows conclusively that no interference was experienced with the transmitter 18.5 kms from the TV Observation vehicle.

26. One other observation needs to made about the data collected. Considering the size and geography of Australia, in a large proportion of circumstances the Frequency Hopping radio would be outside the service area and not between the TV receiver and the TV broadcaster. This would bring into effect the front to back ratio of the TV antenna. Thus the interference would be less than indicated by this Working Paper.

Spectrum caused by Hopping Rise time

27. The working paper also states that the spectrum produced by the rise time of each hop is the significant interfering factor. This is used as a justification in part for the selection of Hop Sets. What is not made clear is the relationship between the spectrum produced by the Hopping Radio, the interference caused, and the selection of Hop Sets.

28. Examination of noise and occupied bandwidth measurements made on Frequency Hopping Radios in Australia suggest that a Hopping Radio does not produce sufficient energy in its generated spectrum to cause adjacent channel interference due the spectrum created by the rise time of each hop. For example with VHF Raven the noise in a 15 kHz bandwidth at 25 kHz separation and 50 kHz separation from the nominal channel frequency is specified as being only 2 dB worse than for digital data mode at 25 kHz separation and identical to digital data mode at 50 kHz separation. Noise drops off rapidly as the separation from the carrier increases. Later in this paper it will be shown that measured data seems to indicate that the interference level is related more to average power. For these reasons it is concluded that the rise time of a Frequency Hopping radio is insignificant in the interference caused to Television systems by Frequency Hopping radios.

Working Paper Conclusions

29. The Working Paper, Reference A, concludes that television reception suffers no perceptible interference from a 50 watt SINCGARS transmission at separations from the television receiver of greater than 18.5 kms, and that as a consequence there should be no restrictions on SINCGARS operation when separated from a TV receiver by more than 18.5 kms.

TECOM Report

30. US Army Test and Evaluation Command produced a supplementary report to the MITRE Working Paper in May 1992. The report basically sets out to evaluate the influence of environmental noise on interference to Television broadcasts, the effect of polarisation, and the directivity of TV antennas.

Test Conduct

31. In the conduct of this test both airborne and ground operation of SINCGARS was evaluated for interference on a single TV Channel. Two different hopsets were used in the testing: one hopset with frequencies only in the 6 MHz covered by the TV channel, and another with all 25 kHz frequencies in the TV channel used and the remainder of the frequencies spread throughout the 30 to 88 MHz band. In the second hopset the TV Channel frequencies comprised 20% of the total frequencies used.

32. Two antennas were used in the test to allow cross polarisation effects to be monitored. A commercial TV antenna was used for television reception and a calibrated log periodic antenna was used for SINCGARS reception. The log periodic was vertically polarised and the commercial antenna horizontally polarised. The antennas were swapped in their roles and orientation to enable cross polarisation effects to be observed. The calibrated log periodic antenna was used as a reference antenna and measurements were taken on a spectrum analyser as well as being monitored on a TV receiver. This allowed both the TV input signal strength and the RF field strength to be calculated.

33. Again the Television Observation vehicle was elevated above the surrounding terrain. The test sites chosen had signal levels well inside the Grade A television contour limits for one TV station, and on the boundary of Grade B television contour limits for another TV station. (The limit for Grade A television reception is approximately 10 dB higher in amplitude i.e. the contour defined by a field strength of -37 dBuV/m.) For ground operation the transmit vehicle proceeded along two roads 65

degrees apart in orientation and the vehicle was between the TV transmitter and TV Observation station.

34. For airborne operation the transmit aircraft was behind the TV antenna pointing towards the TV station. Signals were monitored from the Transmit aircraft up to 30 kms. The aircraft used a 40 Watt SINCGARS station transmitting into an omni-directional aircraft antenna. Tests were performed for both Grade A and Grade B service areas.

Test Results - Ground

35. The test data shows the combination of cross-polarisation and antenna directivity resulted in 19 dB of relative rejection of the SINCGARS signal. There was -12.4 dB of rejection of the SINCGARS signal and a gain to the TV signal of +6.8 dB.

36. The interference was just perceptible on the road which angled the furthest away from the line between the TV transmitter and the TV receiver at 1.9 km. The ratio of the received Protection Ratio, ratio of TV Signal to interfering signal (SINCGARS), at the antenna was 7 dB and at the TV receiver 21 dB. This means the TV antenna resulted in 14 dB of cross polarisation and side lobe rejection of the SINCGARS signal.

37. For the road only 5 degrees away from the line between the TV transmitter and the TV receiver, the interference was just perceptible at 2.9 km. The received Protection Ratio at the antenna was 15 dB and at the TV receiver 23 dB. This means the TV antenna resulted in 8 dB of cross polarisation and side lobe rejection of the SINCGARS signal.

Test Results - Airborne

38. The test data indicates that in the Grade A service area the Hopping Transmission was just perceptible at 17 to 20 kms for received Protection Ratios at the antenna of 5 to 6 dB and at the TV of 24 to 25 dB. This means the TV antenna resulted in 19 dB of cross polarisation and back lobe rejection of the SINCGARS signal.

39. In the Grade B service area the Hopping Transmission was just perceptible at 27 to 28 kms for received Protection Ratios at the antenna of 7 to 8 dB and at the TV of 26 to 27 dB. This means the TV antenna resulted in 19 dB of cross polarisation and back lobe rejection of the SINCGARS signal.

Environmental Noise

40. Sample data was collected of picture quality at Grade-B contour levels in the field with no emissions from SINCGARS present. This was compared with a laboratory generated signal at the same level with no environmental noise. The picture quality of the laboratory signal was obviously superior. Subsequently noise was introduced into the laboratory signal fed to the TV until the Signal to Noise ratio was 20 dB. This picture was better than the field pictures obtained, but worse than the laboratory signal with no noise.

41. The report makes the point that noise needs to be taken into account when determining the level of interference acceptable from a Hopping Radio.

Cross Polarisation

42. The report presents a number of spectrum analyser graphs showing the effect of cross polarisation. One shows the performance of a log-periodic antenna and the other the performance of a commercial TV antenna. The log periodic antenna shows a cross polarisation rejection of at least

12 dB. The commercial antenna shows a cross polarisation rejection of at least 5 dB. This is shown for both the forward and backward directions.

TV Antenna Directivity

43. The report states that virtually all receiving antennas have directional characteristics, but that TV broadcast antennas are rarely collocated.

TECOM Report Conclusion

44. The TECOM Report concludes that further testing should be conducted to determine values that can be applied to the environmental noise, cross-polarisation and directivity characteristics of TV receive antennas.

ITU RECOMMENDATION ITU-R IS.851-1

45. ITU recommendation ITU-R IS.851-1 provides recommendations on the protection levels that should be set for Television Frequencies when being shared with other fixed services or land mobile users. All television transmission formats and their specific variants (NTSC, PAL-D, SECAM) are catered for in the report. The ITU report considers fixed frequency continuous interference and interference which experiences fading and other tropospheric effects.

46. As Frequency Hopping is a time variant process, the levels for Tropospheric interference were chosen as this is the only data in the recommendation which takes some account of time variation in interference.

APPLICATION TO AUSTRALIAN TELEVISION

47. In order to understand the ITU recommendations it is necessary to know the characteristics of Australian Television Channels. In summary Australian Television Channels have the characteristics described in Table 6.

48. The requirements for Tropospheric Interference for a PAL-D, 625 line system are given in Table 7 relative to the bottom band edge. In Table 7, the column for negative modulation type applies. The frequency scale used in the ITU recommendation is relative to the nominal frequency of the vision carrier which is 1.25 MHz above the bottom band edge. Table 7 corrects the frequency scale to make the figures relative to the bottom band edge. The original data can be found in Technical Note, CEU/TNV/0123.

Property	*Value*
Vision Modulation	Vestigial Sideband PAL-D
Channel Bandwidth	7 MHz
Vision Carrier	1.25 MHz above lower edge of channel negative amplitude modulation
Field Frequency	50 Hz
Frame Frequency	25 Hz
Fields per Frame	2
Lines per frame	625 lines (interlaced 2:1)
Line Frequency	15625 Hz
Colour Sub-Carrier	4.4336 MHz
Sound Main Carrier	5.5 MHz above vision carrier
Sound Sub - Carrier	242.19 kHz above main sound carrier
Sound Modulation	FM
Deviation	+/-50 kHz
Pre-Emphasis	50 us

Table 6 Australian Television Channel Characteristics

	Protection Ratio	
	Modulation Type	
Relative[1] Frequency MHz	Positive dB	Negative dB
-12.75	-17	-15
-4.75	-17	-15
-1.25	-1	1
-0.25	-1	1
0	21	23
0.75	42	44
1.25	45	47
1.75	48	50
2.25	48	50
3.25	42	44
4.25	34	36
4.85	43	45
6.05	43	45
7	23	25
7.45	-14	-12
16.25	-14	-12

Table 7 ITU Protection Ratio Australian Television

Note 1. Frequency relative to the bottom edge of the Television Channel.

49. The protection ratio required by the ITU recommendations relative to the band edge is plotted in Figure 1 to give the reader an idea as to the shape of the curve.

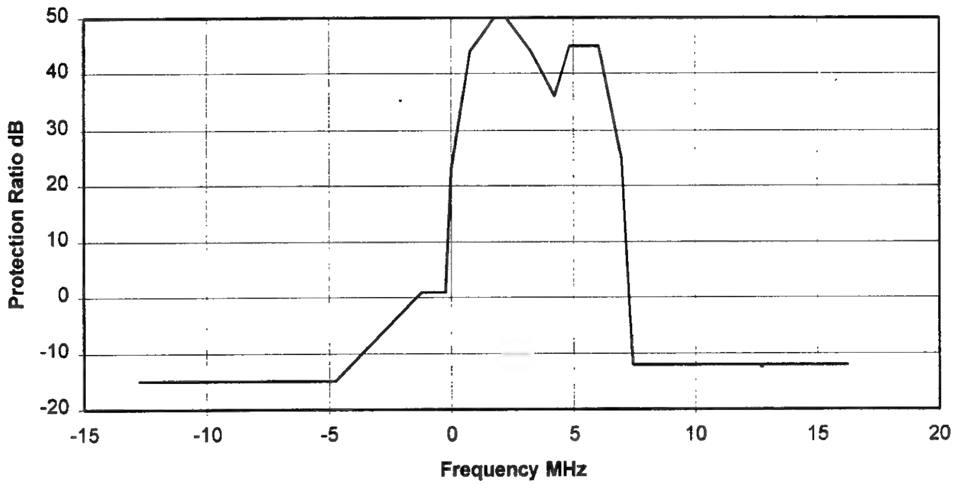

Figure 1 ITU Protection Ratio - Australian Television

50. The Australian television channel allocations of interest in the 30 to 88 MHz band are given in Table 8 below. The table identifies the upper and lower band edge for each channel and gives the associated Channel Number.

	Band Edge (MHz)	
Channel	*Lower*	*Upper*
0	45	52
1	56	63
2	63	70
3	85	92

Table 8 Australian Television Channel Band Edges

DOCA LABORATORY REPORT

MEASURED PROTECTION RATIOS

51. In March 1994 tests were conducted at Department of Communications and the Arts, Communications Laboratory in Canberra. A report was released in April 1994. A number of tests were conducted using a Plisch precision television demodulator, a high quality test monitor, and RAVEN VHF Manpack Frequency Hopping Radio alone and with a 50 Watt power amplifier. Three other Television receivers were also used in the testing to obtain some indication of variation in performance between Television receivers.

52. The tests determined the ratio of the received television signal power to received peak interference that could be tolerated such that interference to the picture test pattern was just

perceptible. This is the protection ratio required to avoid any perceived interference. The tests were conducted for Television Channel 2, which covers 63 to 70 MHz. Table 9 summarises the results obtained.

Hopping Range	Protection Ratio
63 to 70 MHz	42 dB
Full Band 30 to 88 MHz	36 dB
Full Band with 63-65 MHz and 68-69 MHz excluded	36 dB
Full Band with 63 to 70 MHz excluded	-3 dB to 0 dB
Full Band with 59.5 MHz to 73.5 MHz excluded	-20 dB to -12 dB

Table 9 Measured Protection Ratios

53. Five hopsets were used in the tests conducted. These were:

a. hopping on Channel 2 frequencies only;

b. hopping full band with no exclusions;

c. hopping full band with 63-65 MHz and 68-69 MHz from Channel 2 frequencies excluded;

d. hopping full band with all Channel 2 frequencies excluded; and

e. hopping full band with Channel 2 frequencies +/- 3.5 MHz, or and additional half a TV channel either side.

54. The test results in Table 9 were obtained using mainly the Plisch precision television demodulator with a precision monitor. Three additional Television receivers were used for only one test. This resulted in an 8 dB variation in the test results obtained. The US data indicated variations of up to 30 dB were possible. In the light of this it seems likely that the results may vary an unknown amount greater than is currently indicated. The US data cannot be used to estimate this variation because the transmission systems are so different. This leads to the conclusion that a survey of Australian TV receivers is required to ascertain the variation in Australian Television performance.

DOCA FINDINGS

55. The DOCA report discusses conclusions, recommendations and scenarios in a number of places. These findings in the report are summarised below:

a. The required protection ratio for operation in the primary service area of a Television station, with a 50 watt station and a frequency exclusion of the Channel band +/- 3.5 MHz, is -20 dB. This finding allows 10 dB of cross polarisation discrimination and means a minimum distance of 1 km between TV receiver and radio transmitter is required. No allowance is made for TV receive antenna gain and directivity or losses in the transmitting antenna.

b. Second harmonic radiation on the VHF Manpack radio will require additional sub-harmonic exclusions when operating in a primary service area. The frequencies involved are:

(1) Channel 1 30 to 31.5 MHz

(2) Channel 2 31.5 MHz to 35 MHz

(3) Channel 3 42.5 MHz to 46 MHz

c. Television translators are a separate problem and will have to be covered on a case by case basis, because they are usually located on hill tops well outside the 50 uV/meter contour which is normally used as the Primary Service area guide.

d. From 4 to 50 kms beyond the Primary Service area boundary, i.e. 50 uV/meter contour, there exists a possibility of interference depending on the particular radio installation involved. This is based on the following assumptions:

(1) Television antennas are 10 meters high and have a gain of 6 dB and a front to back ratio of 6 dB.

(2) There is no polarisation discrimination available.

(3) A 50 watt station is used with a 30 meter mast with a 0 dBi antenna.

(4) A 50 watt station is used with a 3 meter mast with a 0 dBi antenna.

(5) A 5 Watt station is used with a 3 meter mast and a 0 dBi antenna.

e. Two rules are required:

(1) **Rule 1:** One for operation in the Primary Service area and up to 50 kms beyond the service area boundary. In this case a. and b. above should apply.

(2) **Rule 2:** Beyond 50 kms past the Primary Service area, no exclusions or operating restrictions should apply.

CONSIDERATION OF 2ND HARMONICS

56. Some of the findings indicated above however require some further investigation. For example a 50 Watt station does not require exclusions at sub-harmonic frequencies and a 5 Watt manpack station does. It is argued that the exclusions are required on the basis of harmonic levels emitted by the VHF R/T compared with those emitted from the VHF R/T with power amplifier. However:

a. the harmonics of the 5 watt manpack station are specified as 40 dB below the emitted carrier and in practice are one or two dB better than this;

b. the harmonics of the VHF PA are 30 dB better than those emitted from the VHF R/T as the PA emits 10 dB more power;

c. DOCA test results show that a protection ratio of 42 dB was required, when hopping from 63-70 MHz (the Channel 2 frequency allocation), and when hopping full band from 30 to 88 MHz the protection ratio required was 36 dB; and

d. DOCA test results show that when 63 to 70 MHz is excluded, causing only second harmonics to appear on the Channel 2 allocation, the required protection ratio became between 0 and -3 dB a drop of 42 to 45 dB.

e. DOCA test results show that when 63 to 70 MHz plus an additional 3.5 MHz either side is excluded, causing only second harmonics to appear on the Channel 2 allocation, the required protection ratio became between -12 and -20 dB a drop of 54 to 62 dB

57. If the second harmonics of the VHF R/T were to have a significant impact on required protection ratio, then it could be expected that when the R/T was hopping from 30 - 88 MHz with the TV Channel frequencies barred that the second harmonics would still cause significant interference,

giving rise to a protection ratio greater than could be predicted from the shape of the ITU Protection Ratio curve using peak power of the fundamental and the peak power levels of the harmonics.

58. For example assume the frequency hopping radio is hopping full band, from 30 to 88 MHz, and the 7 MHz of the TV Channel is excluded. If the ITU Protection Ratio curve is examined and only the carrier fundamental frequencies and power are considered, it can be seen that the required Protection Ratio can be estimated to decrease by approximately 40 to 50 dB. This is exactly what happens. The second harmonics did not seem to have an impact.

59. For a second example assume the Frequency Hopping radio is full band hopping, i.e. from 30 to 88 MHz, with 7 MHz of the TV channel and 3.5 MHz either side of the channel barred. The measured protection ratio has changed by 54 to 62 dB depending on the TV receiver. The reduction predicted from the ITU graph occurs indicates a change of 58 to 63 dB if the harmonics are ignored. The results are consistent with the ITU graph, but the harmonics have been ignored.

60. Another way to look at this is to consider the measured protection ratio for full band hopping with the TV channel and 3.5 MHz either side of the channel barred. Whilst the fundamental of each hop will not land within the TV channel, harmonics of the Frequency Hopping radio, as for any other radio, will. The measured protection ratio was -12 to -20 dB depending on the TV receiver. In this case the fundamental of the Frequency Hopping radio is 12 to 20 dB larger than the TV signal being received. Now the harmonics which occur within the TV channel are 40 to 45 dB below the fundamental, so if this difference is subtracted from the protection ratio for the fundamental, the protection ratio for the second harmonics occurring in the TV channel is +20 to +33 dB.

61. Another measurement when taken when hopping just on the TV channel showed the required protection ratio to be 42 dB. The ITU graph indicates 50 dB is required. If peak power levels are considered this would indicate that the second harmonics at this protection ration should still be causing significant interference. Thus the measured protection ratio with only second harmonics landing on the TV channel is 9 to 22 dB below what should be expected from previous measurements. The measurements indicate otherwise. So it appears that the second harmonics have little or no impact on the required protection ratio.

62. The question naturally arises as to why the measured protection ratios do not match with the ITU graph, and why the measurements do not appear to be consistent. The most likely answer is that we have considered only peak power for the fundamental and harmonics, when in fact the change in average power may be far more significant.

63. When full band hopping with the TV Channel excluded, only harmonics appear in the TV channel. Not only are the harmonics at least 40 dB below the fundamental carrier level, but they appear only on every second 25 kHz increment in the TV channel. Further, the time that each harmonic is active is only a small proportion of the total time.

64. It is clear that considering peak power does not explain observed data with regard to harmonics and makes the measured data inconsistent. It is also likely that considering harmonics in terms of average power may offer a better explanation. There is no doubt that effect of harmonics on Television Interference for Frequency Hopping radios using average power can be calculated and then compared against measured data, but this has not be done in this report because it is only a secondary effect when compared to the influence of the fundamental during Frequency Hopping emissions. More work needs to be done in this area, to ascertain and verify whether the interference of harmonics is related to average power.

THEORETICAL MODELLING

65. Theoretical modelling of ITU Protection Ratio recommendations is required to give a better understanding of Protection Ratio requirements and its application to Frequency Hopping radio systems. Verification of the model against experimental data enables the validity of the model to be

checked and also enables the experimental results to be explained in a rigorous manner. Once this has been done the model can then be used to make theoretical predictions about various frequency allocation schemes for hopping radios with some degree of confidence that collection of experimental data would back up the theoretical predictions.

66. There are probably several methods of modelling the impact of Frequency Hopping on Television but the two main ideas behind the modelling are to use either peak power or average power to calculate the effective power incident on the TV channel. The effective power is then compared with the TV signal level to determine the protection ratio.

PREDICTION OF PROTECTION RATIO USING PEAK POWER

67. Using peak power to calculate the Protection Ratio for the scenarios described in Table 9 gives the results shown in Table 10.

Hopping Range	Reduction in Protection Ratio	
	Measured	Calculated
63 to 70 MHz	0 dB	0 dB
Full Band 30 to 88 MHz	6 dB	0 dB
Full Band with 63-65 MHz and 68-69 MHz excluded	6 dB	0 dB
Full Band with 63 to 70 MHz excluded	42 to 45 dB	25 dB
Full Band with 59.5 MHz to 73.5 MHz excluded	54 to 62 dB	60 dB

Table 10 Reduction in Protection Ratio, Peak Power

68. Table 10 indicates that Peak Power has a number of problems. Firstly it does not indicated the reduction in Protection Ratio observed in a variety of scenarios due to hopping over a larger number of channels. This is illustrated by comparing Full Band hopping with hopping just on the 7 MHz of the TV station channel. The line of reasoning for Peak Power would say that because both Hopsets have Peak Power appearing in the most sensitive part of the channel, there should be no reduction in the required Protection Ratio. For Average Power the line of reasoning would say that there should be a reduction in the required Protection Ratio because the Average Power is less.

69. The prediction for Full Band hopping with 63 to 70 MHz excluded can be improved by allowing the points chosen on the ITU curve to vary by 0.25 MHz to allow for variation in TV receiver passband. If the passband was say 0.25 MHz wider on both band edges then the prediction would then be 49 dB which is a bit closer to the 42 to 45 dB observed. The only problem with this is that this amount of error would also have to be allowed for the precision monitor used in DOCA testing, and this may not be reasonable.

70. When considered with information from the previous section on second harmonics it does not appear that Peak Power used as a basis for estimating effective power of the Frequency Hopping radio fits the data.

A THEORETICAL MODEL USING AVERAGE POWER

71. Technical Note CEU/TNV/0124 proposes a suitable model based on Average Power and tests the model against data obtained from the DOCA Laboratory Report. The model and the findings of the technical note are summarised below.

72. The Protection Ratio required to ensure interference free television viewing is a function of frequency. CEU/TNV/0124 models the ITU protection ratio curve using a piece-wise linear approximation. Since the original ITU protection ratio curve is a piece-wise linear construction the model developed models the curve exactly.

73. The technical note proposes that the required Protection Ratio is effectively another way of specifying the system noise floor at any given receive level. The technical note also shows that the Protection Ratio can be interpreted as a gain to be added to the interfering signal level so that the interfering signal level can be compared directly with the wanted Television carrier signal. Such a comparison gives the excess noise ratio which is a measure of the excess noise above the system noise floor and can be calculated from the following.

$$\text{excess\_noise} = (\text{Channel}(f) - \text{Unwanted\_Signal}) - \text{Wanted\_Signal}$$

74. Observation of the parameters involved indicates that the protection ratio is expressed as a function of frequency and when this is combined with the unwanted interfering signal the combined terms need to be integrated over the frequency range of interest.

75. Even further examination of the signals involved in the equation is required, however, because if the interfering signal is a Frequency Hopping signal, then the signal is not time invariant, and there is only a finite probability of the signal appearing at any specific frequency at any given time. Even conceptually, this would suggest that the average power over time on any. frequency of the hopset over which the radio hops would be less than the peak power emitted at any instant of time. The issue needs to be examined theoretically to provide an understanding of measurement results undertaken, and a proper basis for further decision making.

76. Technical Note CEU/TNV/0124 points out that noise power is the average power per unit time and on this basis alone it can be argued that power emitted by a hopping radio should also be averaged over time. The time period of averaging needs to take account of the probability of a frequency being occupied, or the average occupancy rate. The average power in watts/Hz for a hopping radio is actually, the peak power or nominal output power, divided by the frequency span over which the radio is hopping. The average power seen over any given frequency span in the hop set is the average power in watts/Hz multiplied by the frequency span of interest.

77. It should be noted that the ITU recommendations specify relative total power at a specified fixed frequency to the power of the TV transmitter taken over the whole of a 7 MHz channel. The recommendations do not specifically take time averaging into account although the recommendation does make an allowance in some way for time averaging by defining different levels for Tropospheric and Continuous interference. This allowance tends to support the view that an interfering signal should be time averaged even though the TV transmission is not.

78. In the testing performed at DOCA the Channel 2 frequency allocation was used for measurements. And so in examination of the model, CEU/TNV/0124, uses the Channel 2 frequency allocation for calculations. Any of the TV Channels could have been used.

79. Using the protection ratio determined by measurement, the VHF R/T power is calculated relative to the assumed TV Carrier power, and then the average noise power caused by the hopping emission over the Channel 2 frequency allocation is calculated. However this noise power then needs to be multiplied by and integrated with the ITU protection ratio curve over the spectrum of interest to calculate an effective noise power. This is then compared with the actual TV signal to determine the calculated excess noise ratio.

80. Because the ITU recommendations have significant margins built in to allow for variation in television receivers and other irregularities, an excess noise ratio, using this method, of 3 dB is still predicted. However the DOCA measurements have shown that this excess noise ratio was acceptable.

81. What is important however, is that when this level is used as a reference point and then calculations are performed to determine the expected change in required protection ratio we obtain the results in Table 11.

Hopping Range	Reduction in Protection Ratio	
	Measured	Calculated
63 to 70 MHz	0	0
Full Band 30 to 88 MHz	6	9.18 dB
Full Band with 63-65 MHz and 68-69 MHz excluded	6	11.91 dB
Full Band with 63 to 70 MHz excluded	42 to 45	43.82 dB
Full Band with 59.5 MHz to 73.5 MHz excluded	54 to 62	63.78 dB

Table 11 Reduction in Protection Ratio, Average Power

82. A comparison of the measured results against predicted results shows in general good agreement when measurement error is allowed for. It is estimated that results are generally only repeatable within +/-2 dB. However, there are several points where there seems to be some error in the measurements made. For example, while it seems possible that the reduction in protection ratio required when going from hopping only on the Channel 2 allocated band to full band hopping is only 6 dB for the television receiver used it seems highly unlikely that the barring 4 MHz of the Channel 2 band should produce no change from full band hopping, especially when excluding the other three megahertz results in 42 to 45 dB measured reduction.

83. There are several sources of error that may have occurred or may be contributing to the result variation. Some of these are:

a. variation in the pass-band of television receivers both between receivers and from the ITU characteristic published in ITU-R IS.851-1,

b. variation in measured results due to measurement error;

c. incorrect setting of barred bands on the VHF Frequency Hopping Unit.

84. Despite some minor discrepancies between the measured results, which have internal inconsistencies, and the theoretical model it seems reasonable to conclude that the Average Power model does explain the interference mechanism more satisfactorily and provide an accurate method for predicting changes in Protection Ratio. It also seems reasonable to conclude that additional work in characterising more carefully the pass-band characteristics, and protection ratio characteristics of various TV receivers would produce a more accurate model, or give more confidence in the existing model.

ANTENNAS IN USE WITH ARMY

85. Another important consideration in determining exactly what nominal protection ratio may be achieved with various radio configurations used by Defence is the antenna used on the Frequency Hopping radios under consideration.

86. Antennas in use by Defence with Frequency Hopping radios fit into four categories. These are:

a. Manpack Radio antennas fitted directly to the radio. ATEA has measured many such antennas in the last few years, none has ever recorded a gain higher than -5 dBi and gains may be as low as -35 dBi at some frequencies for some antennas. Some effort could be expended in characterising further the particular manpack antennas in service to verify existing data and determine the consistency of that data. The antenna height in use is never greater than 1.5 meters at the antenna base.

b. Broadband vehicle whips fitted on military vehicles. These antennas have a specified gain, when mounted on a ground plane 3 meters square. The specified gain varies between -3 dB and +1 dB over that of a ¼ wavelength monopole, thus the maximum specified gain is approximately 2 dBi. The measured gain though is never realised in practice as the antennas are mounted on vehicles of all metallic construction, often next to roll bars and exhibit generally a high VSWR. Nominating a gain of 0 dBi would be more than generous for these antennas in use. The base of the vehicle whip for FFRs is approximately 1.5 meters above ground.

c. Mast mounted antennas omni-directional whip antennas. Again these antennas have a specified gain when mounted on a mast. The specified gain varies between -3 dBc and 0 dBc or -1 dBi to + 2 dBi. The antenna height is 10 meters.

d. A high gain antenna has been evaluated. The gain of the high gain antenna, excluding any cable losses, is between +5 dBi at the bottom of the band and greater than +20 dBi in the middle of the band. This applies to both horizontal and vertical polarisation. The minimum front to back ratio is 10 dB and for frequencies above 45 MHz is above 25 dB, increasing to 30 dB between 60 and 70 MHz and increasing to above 35 dB at 90 MHz. The mast height is 6 meters. The net gain from the rear after subtracting the front to back ratio from the forward gain is 1.6 dBi at 30 MHz and less than -5 dBi from 40 to 90 MHz.

CALCULATION OF PATHLOSS

87. A suitable technique is required to calculate pathloss between sites so that the signal level of a Frequency Hopping signal at the Television receiver can be calculated. A suitable method is identified in Technical Note CEU/TNV/0121. This note uses the method identified in ITU Recommendation PN.370.6, VHF & UHF Propagation Curves for the Frequency Range 30 to 1000 MHz. The note derives from the curves in PN370.6 an expression for calculating the received signal strength directly in dBuV/m for distances up to 200 km. The expression derived takes account of the transmitting antenna height for the hopping station whilst assuming the Television receiver antenna is at 10 meters. Other factors taken into account are the transmit power, transmit antenna gain, Television receiver front to back ratio. An expression is then derived which calculates directly the protection ratio at the Television receiver site.

PREDICTED PROTECTION RATIOS

HOPPING WITHIN TELEVISION SERVICE AREAS

88. US Data includes data with a Frequency Hopping radio operating within the Television Service area. Depending on the location of the receiver, and the Television Station field strength at the receiving location, separation distances were determined when interference was just perceptible. These distances were as low as 2.9 kms. The DOCA report makes recommendations on the use of Frequency Hopping in Primary Service areas in Australia. However, the measurement data on which these recommendations are based, and the assumptions about Army radio systems, mean these recommendations may need revision. What the US Data and DOCA report do indicate is that Frequency Hopping is possible in the Primary Service Area of a Television station. The question is what restrictions need to be applied.

89. This report does not consider Frequency Hopping within the Primary Service area because of the uncertainty of the available data and because there is insufficient data to completely evaluate the theoretical models, which are required to understand exactly what the measurements mean. This leads to the need to do further measurements to backup data already obtained and enable a theoretical model to be refined and verified.

HOPPING OUTSIDE TELEVISION SERVICE AREAS

90. Using the pathloss calculation method described above, and using the antenna data also described, it is possible to make accurate predictions as to Protection Ratios achieved in various scenarios. These scenarios all consider operation outside the Primary Service area. Calculations have been performed for two basic classes of operation, full band hopping which according to DOCA measured data requires a protection ratio of 36 dB, and full band hopping with on the TV channel (7 MHz) barred, which requires a protection ratio of 0 dB.

FULL BAND HOPPING 30 - 88 MHZ

91. The calculation performed in CEU/TNV/0121 indicate the following:

a. The Manpack configuration can operate full band hopping 1 km outside the Primary Service area.

b. The Vehicle configuration at 50 Watts can operate full band hopping 19 km outside the Primary Service area.

c. A 50 Watt station using an omni-directional antenna mounted on a 10 meter mast can operate full band hopping 31 km outside the Primary Service area.

d. A 50 Watt station using an High Gain Directional antenna mounted on a 6 meter mast pointed away from the service area can operate full band hopping 16 km outside the Primary Service area.

FULL BAND HOPPING WITH 63 TO 70 MHZ EXCLUDED.

92. The calculation performed in CEU/TNV/0121 indicate the following:

a. The Manpack configuration can operate full band hopping with 63 MHz to 70 MHz excluded less than 1 km outside the Primary Service area. No additional guard bands are required.

b. The Vehicle configuration at 50 Watts can operate full band hopping with 63 MHz to 70 MHz excluded less than 1 km outside the Primary Service area.

c. A 50 Watt station using an omni-directional antenna mounted on a 10 meter mast can operate full band hopping with 63 MHz to 70 MHz excluded less than 1 km outside the Primary Service area.

d. A 50 Watt station using an High Gain Directional antenna mounted on a 6 meter mast pointed away from the service area can operate full band hopping with 63 MHz to 70 MHz excluded less than 1 km outside the Primary Service area.

RELIABILITY OF PREDICTIONS.

93. The calculations performed in CEU/TNV/0121 are based on data with unknown certainty. For example the variation in Protection Ratio with a variety of TV receivers is unknown. The variation in commercial TV Antenna characteristics such as gain, directivity, front to back ratio and cross polarisation rejection have only been estimated from estimated from known Antenna characteristics. TV antennas may offer significantly better performance than estimated, or worse performance. On top of this Pathloss calculations are used which have been obtained empirically and statistically evaluated. Actual performance because of terrain variation may not agree with the predictions. For

this reason, it is concluded that field trials need to be conducted to establish the veracity of the predictions.

CONCLUSION

94. It is concluded from reviewing the US data that:

a. a 50 Watt SINCGARS Frequency Hopping station produced no interference, when ground based and 18.5 kms or greater from the victim receiver, or when airborne and 28 kms or greater from the victim receiver. Therefore no restrictions on SINCGARS operation should be applied when separated from a TV receiver by more than these distances;

b. the variation in US Television set protection ratios is of the order of 30 dB and no similar data exists for Australian Television sets. A survey of Australian Television sets is required to ascertain the range of responses expected in Television sets in the Australian Market;

c. that the field testing scenario, with the interfering Frequency Hopping radio between the TV station and the victim receiver, was a worst case situation and interference would be less than indicated by US Data for large proportion of scenarios in Australia;

d. the frequency spectrum generated by Frequency Hopping radios is not significantly worse than for normal fixed frequency operation and the rise time of a Frequency Hopping Radio is insignificant in the interference caused to Television systems by Frequency Hopping radios.

e. natural interference at Grade-B contour levels (47 dBuV/m) is worse than a Signal to Noise ratio of 20 dB and cross polarisation rejection of at least 5 dB is available for commercial antennas in both the forward and backward directions. Therefore environmental noise, cross polarisation rejection, and antenna directivity need to be taken into account when determining the level of interference acceptable from a Hopping radio. However, further work needs to be performed to quantify the levels that should be used.

95. Further analysis as a result of investigation into the impact of ITU-R IS.851-1 has shown that many of the assumptions made in the DOCA report, due to lack of data, need revision. From an examination of the data contained in the DOCA report and analysis using two possible theoretical models it is concluded that:

a. the DOCA finding that 2nd harmonics are a significant factor in VHF Manpack Operation are not supported by the data, and that 2nd harmonics have little or no impact on the required protection ratio;

b. the use of peak power to explain measurements with respect to harmonics does not explain the data and makes the measurement data inconsistent;

c. predictions of change in Protection Ratio based on Peak Power predictions do not fit the measurement data in the DOCA report while predictions of change in Protection Ratio based on Average Power approximate the measurement data, and have the correct data trends, without reference to 2nd harmonics;

d. the measurement data has inconsistencies when viewed in the light of both theoretical models. This may be due to errors in either the theoretical models or the measurement data;

e. the measurement data was obtained for three commercial television receivers and the variation in results due to different Australian Television receivers is unknown and cannot be predicted from US data due to the different transmission formats.

96. An examination of Army Antennas in use shows that assumptions about Army Antennas used in the DOCA report were incorrect and thus reported predictions are based on incorrect assumptions.

97. It is concluded that the predicted separation distances between Frequency Hopping radios and Television receivers based on ITU recommendations and DOCA measurements indicate that Frequency Hopping can take place outside the Primary Service area with separation distances significantly reduced from those suggested in the DOCA report.

98. Calculations show that full band hopping (30 - 88 MHz) can be used with:

a. the Manpack configuration 1 km outside the Primary Service area.

b. the Vehicle configuration at 50 Watts 19 km outside the Primary Service area.

c. a 50 Watt station using an omni-directional antenna mounted on a 10 meter mast 31 km outside the Primary Service area.

d. a 50 Watt station using an High Gain Directional antenna mounted on a 6 meter mast pointed away from the service area 16 km outside the Primary Service area.

99. Calculations show that full band hopping (30 - 88 MHz) with the TV station channel excluded can be used with all configurations identified above at less than 1 km outside the Primary Service area.

100. It is concluded that operation inside the Primary Television Service area has not been considered in this report and that further work needs to be performed in this area to ascertain what restrictions on operation are required.

RECOMMENDATIONS

101. It is recommended that:

a. a field trial and field testing be conducted to verify the recommended operating distances for different operating configurations;

b. a selection of Australian Television sets be measured to determine the variation in Protection Ratio between Television sets;

c. a selection of Australian TV antennas be purchased and tested for gain, directivity, front to back ratio, and cross-polarisation characteristics;

d. field and laboratory testing be performed to ascertain the level of environmental noise experienced in Australian Television conditions;

e. that further testing be performed to examine more closely the nature of Frequency Hopping interference so that a theoretical model can be refined and verified;

f. a further report be commissioned on the impact of Frequency Hopping within a Primary Service area.

g. ATEA, who has the necessary systems engineering skills and independence, be tasked to perform the additional measurements and investigation required to perform this work.

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ANNEX A
ACRONYMS AND ABBREVIATIONS

dB	The standard unit for expressing transmission gain or loss and relative power ratios. The formula for a decibel is given as: $$dB = 10 * \log_{10} (P_1/P_2)$$ If a ratio of voltages or currents is used then the formula is: $$dB = 20 * \log_{10} (V_1/V_2)$$
dBm	decibels relative to one milliwatt, a measure of absolute power. Zero dBm = 1 milliwatt
DOCA	Australian Government Department, Department of Communications and the Arts.
EW	Electronic Warfare.
FCC	Federal Communications Commission, USA.
HF	High Frequency, 3 to 30 MHz.
Hz	Hertz, the international unit denoting 1 cycle per second.
ITU	International Telecommunications Union.
km(s)	kilometer(s)
MHz	MEGAHERTZ, a unit denoting 1 million (10^6) Hz.
PM	Programme Manager
RAVEN	Project name for the Australian Army's development and procurement program which had the original intent to replace all in-service Army radio systems.
SINCGARS	Single Channel Ground Airborne Radio System, a US Army radio system.
TV	Television.
TVI	Television Interference.
uV/m	microvolt per meter, a measure of RF field strength.
VHF	Very High Frequency, 30 to 300 MHz but used within this report to refer mainly to 30 to 88 MHz.

ANNEX B
DEFINITIONS

Frequency Hopping	is the repeated switching of the instantaneous frequency during radio transmission according to a specified algorithm, to minimise unauthorised interception or jamming of telecommunications. *Note:* The specified algorithm usually selects frequencies in a pseudo random manner. The overall bandwidth required for frequency hopping is much wider than that required to transmit the same information using only one carrier frequency.
Hopset	is the set of single channel frequencies over which a Frequency Hopping radio hops, usually in a pseudo random manner.
Protection Ratio	is the ratio of the TV signal level to the interfering signal level, given in dB, required to error interference free TV reception at the edge of the Television Service area.

Title:	Sharing Between Receiver/Transmitter RT-F200 and VHF Broadcast Services	Issue: 1
		Author: Graeme G. Glenn

References:

A. ITU Recommendation PN.370.6, VHF & UHF Propagation Curves for the frequency range from 30 MHz to 1000 MHz.

Purpose:

Discussion

1 ITU Recommendation Ref. A, PN.370.6, VHF & UHF provides field strength predictions for the VHF frequency range. The field strength predictions are for 1 kW output power from a half-wave dipole.

2 The field strength predictions need to be corrected for transmitter antenna height, output power, and antenna gain.

3 Predictions are valid for distances beyond the radio horizon which is specified as:

Radio_Horizon =4.1*SQRT(height_antenna) km [1]

Where: the Radio_Horizon is calculated in kms
the antenna height, height_antenna, must be given in meters.

4 The following table gives the radio horizon

Antenna Height	Radio Horizon
1	4.10 kms
1.5	5.02 kms
2	5.80 kms
3	7.10 kms
4	8.20 kms
5	9.17 kms
10	12.97 kms

5 For antenna heights, Ha, of less than 37.5 meters the graph figures in Ref. A are corrected by increasing the distance from the source, D, to give a corrected distance, Dc, using the following formula:

Dc =D + 25 - 4.1*SQRT(Ha) [2]

6 For example the following table gives the corrected distance, Dc, for distance D = 20 kms at various antenna heights.

Antenna Height	Corrected Distance
1	30.90 kms
1.5	29.98 kms
2	29.20 kms
3	27.90 kms
4	26.80 kms
5	25.83 kms
10	22.03 kms

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		Author:	Graeme G. Glenn

Discussion cont:

7 Using Figure 1a of Ref. A and the corrected distances, the following Field Strength's are obtained

Antenna Height	Corrected Distance	
1	42.00	dBuV/m
1.5	42.00	dBuV/m
2	42.00	dBuV/m
3	43.00	dBuV/m
4	45.00	dBuV/m
5	45.00	dBuV/m
10	49.00	dBuV/m

8 The following table gives the field strength from Figure 1a of Ref A, and the log of the distance.

Distance kms	Field Strength dbuV/m	
10	64.00	dBuV/m
20	50.00	dBuV/m
50	30.00	dBuV/m
100	15.00	dBuV/m
200	0.00	dBuV/m

Distance LOG10(km)
1
1.30103
1.69897
2
2.30103

9 The values from the graph are however a straight line on log - linear paper for distances up to 200 kms. There for the relationship between distance and dBuV/m is given by:

dbuV/m=a*log10(km)+c [3]

where a and c are constants.

10 Using simultaneous equations it can be found that: a = -49.19179

and c = 113.19179

11 This gives the following calculated values which compare favourably with those from the table above.

Distance kms	Field Strength* dbuV/m	
10	64.00	dBuV/m
20	49.19	dBuV/m
50	29.62	dBuV/m
100	14.81	dBuV/m
200	0.00	dBuV/m

*for 1 kW into half wave dipole

12 Allowing for a nominal power output of Pw watts and an antenna gain, Gi dB, above that for an isotropic radiator, equation [3] becomes:

dbuV/m=-49.19*log10(km)+10*log10(Pw)+Gi+81 [4]

Title:	Sharing Between Receiver/Transmitter RT-F200 and VHF Broadcast Services	Issue: 1
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Discussion cont:

13 Correcting equation [4] for transmitting antenna height, Ha, as per Ref. A produces the following expression:

dbuV/m=-49.19*log10(km + 25 - 4.1*SQRT(Ha))+10*log10(Pw)+Gi+81 [5]

14 For Vehicle and manpack operation the antenna height above the surrounding terrain is 1.5 meters. The radio horizon in this case is therefore 5 kms (see 4 above.)

15 The field strength for various distances assuming 0 dBi antennas are given in the following tables.

Manpack Station (5 W), 0 dBi ant

Distance kms	Field Strength* dbuV/m	
5	19.24	dBuV/m
10	15.35	dBuV/m
15	12.05	dBuV/m
20	9.20	dBuV/m
30	4.43	dBuV/m
40	0.53	dBuV/m
50	-2.76	dBuV/m
60	-5.62	dBuV/m
70	-8.13	dBuV/m
80	-10.39	dBuV/m
90	-12.42	dBuV/m
100	-14.28	dBuV/m

Vehicle Station (50 W), 0 dBi ant.

Distance kms	Field Strength* dbuV/m	
5	29.24	dBuV/m
10	25.35	dBuV/m
15	22.05	dBuV/m
20	19.20	dBuV/m
30	14.43	dBuV/m
40	10.53	dBuV/m
50	7.24	dBuV/m
60	4.38	dBuV/m
70	1.87	dBuV/m
80	-0.39	dBuV/m
90	-2.42	dBuV/m
100	-4.28	dBuV/m

15 The field strength for various distances assuming a -5 dBi antenna for the manpack radio at 1.5 m, and +2 dBi antenna at 10 meters for the Vehicle station is given in the following tables.

Manpack Station (5 W) -5 dBi ant.

Distance kms	Field Strength* dbuV/m	
5	14.24	dBuV/m
10	10.35	dBuV/m
15	7.05	dBuV/m
20	4.20	dBuV/m
30	-0.57	dBuV/m
40	-4.47	dBuV/m
50	-7.76	dBuV/m
60	-10.62	dBuV/m
70	-13.13	dBuV/m
80	-15.39	dBuV/m
90	-17.42	dBuV/m
100	-19.28	dBuV/m

Vehicle Station (50 W), +2 dBi ant, mast 10m.

Distance kms	Field Strength* dbuV/m	
5	39.42	dBuV/m
10	33.92	dBuV/m
15	29.55	dBuV/m
20	25.93	dBuV/m
30	20.12	dBuV/m
40	15.57	dBuV/m
50	11.81	dBuV/m
60	8.62	dBuV/m
70	5.84	dBuV/m
80	3.38	dBuV/m
90	1.18	dBuV/m
100	-0.82	dBuV/m

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Discussion cont:

16 Allowing for TV receiver antenna gain and front to back ratio, the protection ration achieved relative to the wanted signal level is shown in the tables below.

R/T Antenna Gain dBi	0.00
R/T Output Power (W)	5.00
R/T Ant. Height (m)	3.00
TV Antenna Gain (dB)	6.00
TV Ant. F/B Ratio (dB)	6.00
Wanted Signal (dBuV)	50.00

Manpack Station (5 W)

Distance kms	Protection Ratio dB
5	34.90 dB
6	35.81 dB
7	36.69 dB
8	37.53 dB
9	38.34 dB
10	39.12 dB
11	39.87 dB
12	40.60 dB
13	41.30 dB
14	41.98 dB
15	42.64 dB

R/T Antenna Gain dBi	0.00
R/T Output Power (W)	50.00
R/T Ant. Height (m)	3.00
TV Antenna Gain (dB)	6.00
TV Ant. F/B Ratio (dB)	6.00
Wanted Signal (dBuV)	50.00

Vehicle Station (50 W)

Distance kms	Protection Ratio dB
10	29.12 dB
11	29.87 dB
12	30.60 dB
13	31.30 dB
14	31.98 dB
15	32.64 dB
16	33.28 dB
17	33.90 dB
18	34.50 dB
19	35.09 dB
20	35.66 dB

R/T Antenna Gain dBi	-5.00
R/T Output Power (W)	5.00
R/T Ant. Height (m)	1.50
TV Antenna Gain (dB)	6.00
TV Ant. F/B Ratio (dB)	6.00
Wanted Signal (dBuV)	50.00

Manpack Station (5 W)

Distance kms	Protection Ratio dB
5	41.76 dB
6	42.60 dB
7	43.40 dB
8	44.18 dB
9	44.93 dB
10	45.65 dB
11	46.36 dB
12	47.03 dB
13	47.69 dB
14	48.33 dB
15	48.95 dB

R/T Antenna Gain dBi	0.00
R/T Output Power (W)	50.00
R/T Ant. Height (m)	1.50
TV Antenna Gain (dB)	6.00
TV Ant. F/B Ratio (dB)	6.00
Wanted Signal (dBuV)	50.00

Vehicle Station (50 W)

Distance kms	Protection Ratio dB
15	33.95 dB
16	34.55 dB
17	35.14 dB
18	35.71 dB
19	36.26 dB
20	36.80 dB
21	37.33 dB
22	37.85 dB
23	38.35 dB
24	38.84 dB
25	39.32 dB

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R/T Antenna Gain dBi	2.00
R/T Output Power (W)	50.00
R/T Ant. Height (m)	10.00
TV Antenna Gain (dB)	6.00
TV Ant. F/B Ratio (dB)	6.00
Wanted Signal (dBuV)	50.00

Vehicle Station (50 W)

Distance kms	Protection Ratio dB	
1	10.86	dB
2	12.44	dB
3	13.91	dB
4	15.29	dB
5	16.58	dB
6	17.80	dB
7	18.95	dB
8	20.04	dB
9	21.09	dB
10	22.08	dB
11	23.03	dB

R/T Antenna Gain dBi	2.00
R/T Output Power (W)	50.00
R/T Ant. Height (m)	10.00
TV Antenna Gain (dB)	6.00
TV Ant. F/B Ratio (dB)	6.00
Wanted Signal (dBuV)	50.00

Vehicle Station (50 W)

Distance kms	Protection Ratio dB	
25	33.17	dB
26	33.74	dB
27	34.29	dB
28	34.83	dB
29	35.36	dB
30	35.88	dB
31	36.38	dB
32	36.87	dB
33	37.35	dB
34	37.82	dB
35	38.28	dB

R/T Antenna Gain dBi	-5.00
R/T Output Power (W)	50.00
R/T Ant. Height (m)	6.00
TV Antenna Gain (dB)	6.00
TV Ant. F/B Ratio (dB)	6.00
Wanted Signal (dBuV)	50.00

Vehicle Station (50 W)

Distance kms	Protection Ratio dB	
1	22.18	dB
2	23.48	dB
3	24.71	dB
4	25.86	dB
5	26.96	dB
6	28.01	dB
7	29.00	dB
8	29.95	dB
9	30.86	dB
10	31.74	dB
11	32.58	dB

R/T Antenna Gain dBi	-5.00
R/T Output Power (W)	50.00
R/T Ant. Height (m)	6.00
TV Antenna Gain (dB)	6.00
TV Ant. F/B Ratio (dB)	6.00
Wanted Signal (dBuV)	50.00

Vehicle Station (50 W)

Distance kms	Protection Ratio dB	
10	31.74	dB
11	32.58	dB
12	33.39	dB
13	34.16	dB
14	34.91	dB
15	35.64	dB
16	36.34	dB
17	37.02	dB
18	37.68	dB
19	38.32	dB
20	38.94	dB

Title:	**CCIR Protection Ratios for Australian Television Channels sharing with Fixed and Mobile stations causing Tropospheric or equivalent interference in the 30 to 88 MHz band.**	**Issue:** 1	**Author:** Graeme G. Glenn

References:

A. CCIR Recommendation ITU-R IS851-1, Sharing between the Broadcasting Service and the Fixed and/or Mobile Services in the VHF and UHF Bands.

Purpose: To detail the protection ratios required by CCIR Recommendation ITU-R IS851-1 for Trophospheric type interference for Australian Television Channels.

Discussion:

1 Australian Television Channels have the following characteristics:

Modulation Type	Vestigial Sideband PAL-D
Channel Bandwidth	7 MHz
Vision Carrier	1.25 MHz above lower edge of channel negative amplitude modulation
Field Frequency	50 Hz
Frame Frequency	25 Hz
Fields per Frame	2
Lines per frame	625 lines (interlaced 2:1)
Line Frequency	15625 Hz
Colour Sub-Carrier	4.4336 MHz
Sound Main Carrier	5.5 MHz above vision carrier
Sound Sub - Carrier	242.19 kHz above main sound carrier
Sound Modulation	FM
Deviation	+/-50 kHz
Pre-Emphasis	50 us

2 CCIR Rec. ITU-R IS.851-1 requirements for Troposheric Protection for a PAL-D, 625 line system are given in the table below:

Relative[1] Frequency MHz	Protection Ratio Modulation Type Positive dB	Negative dB	25kHz Delta[2] dB
-14	-17	-15	0
-6	-17	-15	0.1143
-2.5	-1	1	0
-1.5	-1	1	2.2
-1.25	21	23	0.7
-0.5	42	44	0.15
0	45	47	0.15
0.5	48	50	0
1	48	50	-0.15
2	42	44	-0.2
3	34	36	0.375
3.6	43	45	0
4.8	43	45	-0.5263
5.75	23	25	-2.0556
6.2	-14	-12	0
15	-14	-12	0

Table 1 Protection Ratio - Tropospheric Conditions

Note[1]

Frequency relative to the nominal carrier frequency which is 1.25 MHz above the bottom of the bottom band edge.

Note[2]

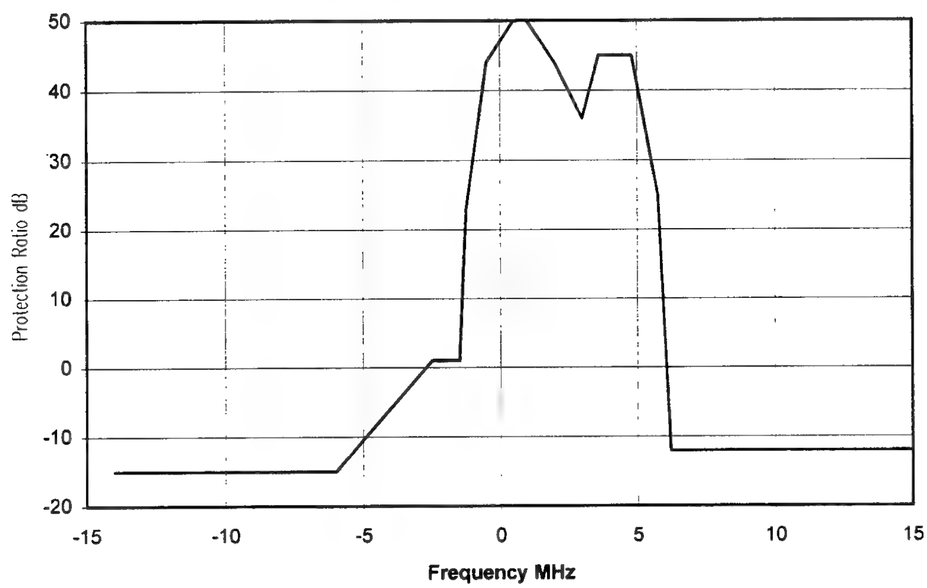
The increment in dB for each 25 kHz channel to achieve the required protection value in the table. Eg commencing with -15 dB at -14 MHz the increment for each 25 kHz channel untill -6 MHz is reached is 0.114286 dB

Title:	**CCIR Protection Ratios for Australian Television Channels sharing with Fixed and Mobile stations causing Tropospheric or equivalent interference in the 30 to 88 MHz band.**	**Issue:** 1	**Author:** Graeme G. Glenn

Discussion cont:

3 For Australian Television channels which have a negatively modulated vision carrier the protection ratio is graphed in relationship to the vision carrier nominal frequency which is 1.25 MHz above the bottom of the channel.

Figure 1 Protection Ratio for Australian TV Channels



Title:	**CCIR Protection Ratios for Australian Television Channels sharing with Fixed and Mobile stations causing Tropospheric or equivalent interference in the 30 to 88 MHz band.**	**Issue:** 1 Author: Graeme G. Glenn

Discussion cont:

4 Relating the data to the bottom edge of the channel produces Table 2

Relative[1] Frequency MHz	Protection Ratio Modulation Type Positive dB	Negative dB	25kHz Delta[2] dB
-12.75	-17	-15	0
-4.75	-17	-15	0.1143
-1.25	-1	1	0
-0.25	-1	1	2.2
0	21	23	0.7
0.75	42	44	0.15
1.25	45	47	0.15
1.75	48	50	0
2.25	48	50	-0.15
3.25	42	44	-0.2
4.25	34	36	0.375
4.85	43	45	0
6.05	43	45	-0.5263
7	23	25	-2.0556
7.45	-14	-12	0
16.25	-14	-12	0

Table 2 Protection Ratio Australian Television[1]

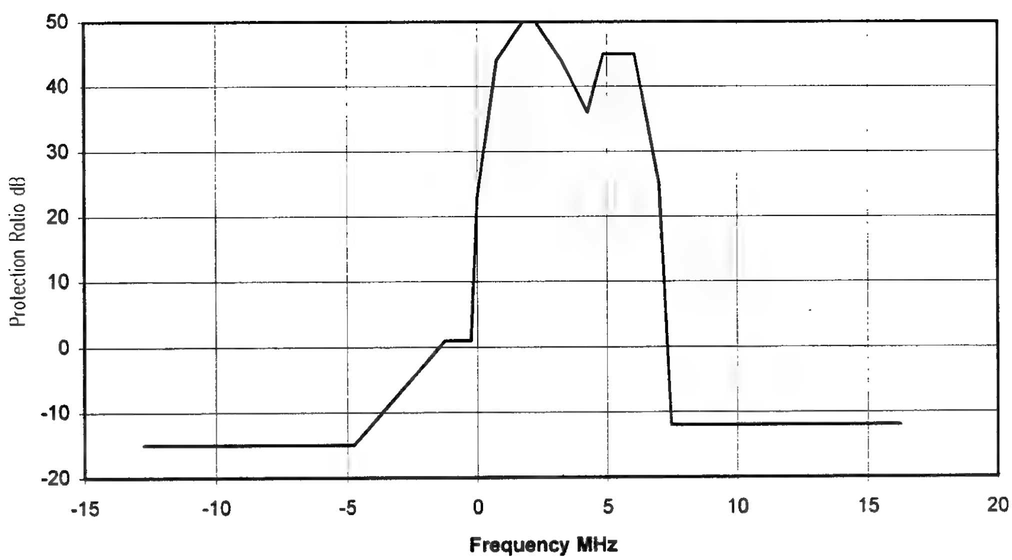
Note[1]

Frequency relative to the bottom edge of the Television Channel.

Note[2]

The increment in dB for each 25 kHz channel to achieve the required protection value in the table. Eg commencing with -15 dB at -12.75 MHz the increment for each 25 kHz channel untill -4.75 MHz is reached is 0.114286 dB

Figure 2 Protection Ratio - Australian Television relative to lower channel edge



Title:

Theoretical analysis of CCIR Protection Ratios for Australian Television Channels for the RAVEN VHF Frequency Hopping Modulation scheme.

References:

A. CCIR Recommendation ITU-R IS.851-1, Sharing between the Broadcasting Service and the Fixed Frequency and/or Mobile Services in the VHF and UHF Bands.
B. Laboratory Report, Defence Department Raven Radio Investigations, No 94-9, Maurie Daly, Department of Communications and the Arts.

Purpose:

The purpose of this technical note is to analyse from a theoretical perspective the effect of various Frequency Hopping schemes on Australian Television channels based on CCIR Protection Ratio information and to correlate theoretical predictions with measured laboratory results.

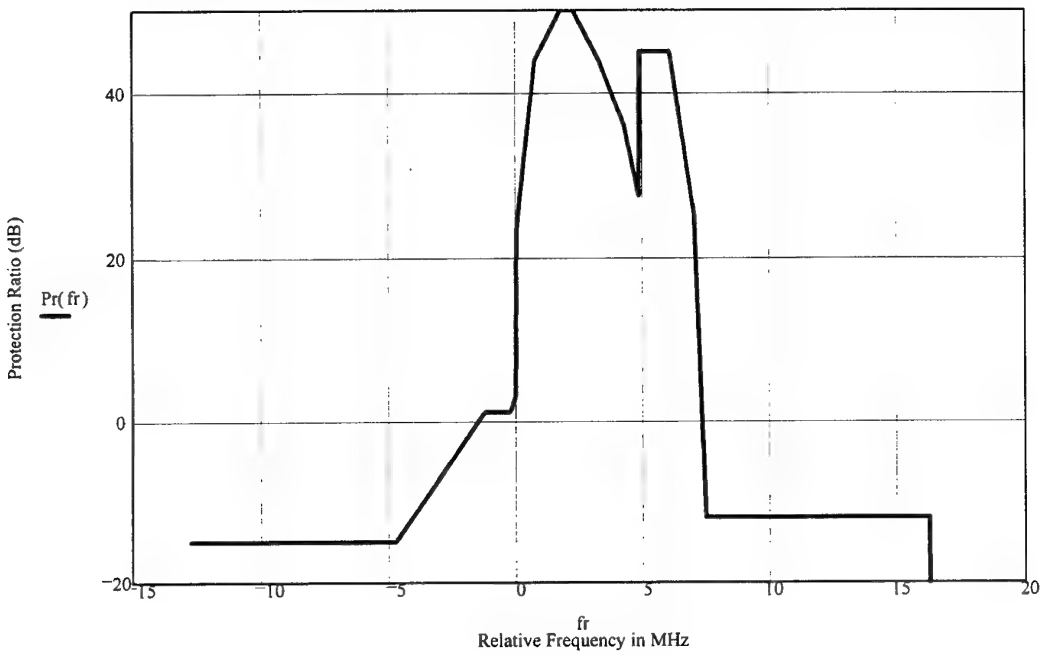
Discussion:

1. ITU-R IS.851-1 defines the protection ratio to be applied to the 625-line, PAL-D, television system which is in use in Australia. This protection ratio can be translated into the following piecewise linear function, Pr(fr), which is a function of frequency, (fr) in MHz, relative to the bottom band edge:

$$Pr(fr) = \begin{cases} -50 & \text{if } fr < -12.75 \\ -15 & \text{if } -12.75 \le fr \le -4.75 \\ -15 + 16 \cdot \frac{fr + 4.75}{3.5} & \text{if } -4.75 < fr \le -1.25 \\ 1 & \text{if } -1.25 < fr \le -0.25 \\ \left[1 + \frac{22}{2.5} \cdot (fr + 0.25)\right] & \text{if } -0.25 < fr \le 0 \\ \left[23 + \frac{21}{0.75} \cdot (fr)\right] & \text{if } 0 < fr \le 0.75 \\ \left[44 + \frac{3}{0.5} \cdot (fr - 0.75)\right] & \text{if } 0.75 < fr \le 1.25 \\ \left[47 + \frac{3}{0.5} \cdot (fr - 1.25)\right] & \text{if } 1.25 < fr \le 1.75 \\ 50 & \text{if } 1.75 < fr \le 2.25 \\ (50 - 6 \cdot (fr - 2.25)) & \text{if } 2.25 < fr \le 3.25 \\ (44 - 8 \cdot (fr - 3.25)) & \text{if } 3.25 < fr \le 4.25 \\ \left[36 - \frac{9}{0.6} \cdot (fr - 4.25)\right] & \text{if } 4.25 < fr \le 4.85 \\ 45 & \text{if } 4.85 < fr \le 6.05 \\ \left[45 - \frac{20}{0.95} \cdot (fr - 6.05)\right] & \text{if } 6.05 < fr \le 7 \\ \left[25 - \frac{37}{0.45} \cdot (fr - 7)\right] & \text{if } 7 < fr \le 7.45 \\ -12 & \text{if } 7.45 < fr \le 16.25 \\ (-50) & \text{otherwise} \end{cases} \qquad [1]$$

2. A plot of Pr(fr) with respect to relative frequency shows the exact shape of the protection ratio requirement relative to the bottom band edge of an Australian Television station.

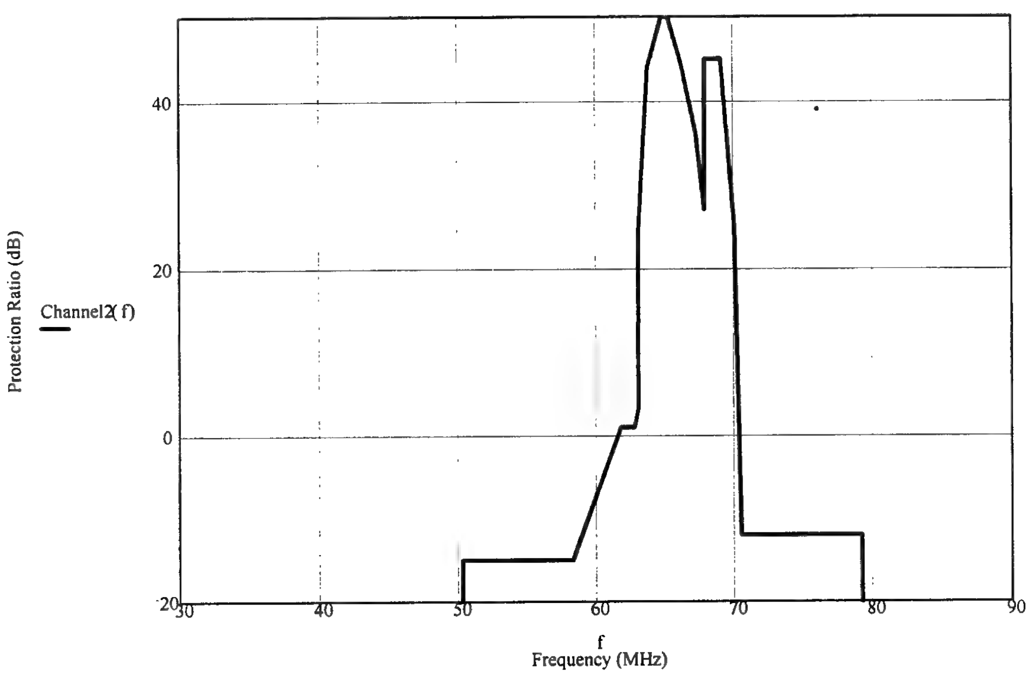
fr := - 12.75, - 12.725 .. 16.25 MHz



3. Choosing Channel 2 which has a bottom band edge frequency of 63 MHz the protection ratio for Channel 2 would be:

$$\text{Channel2}(f) = \text{Pr}(f - 63)$$

$$f = 30, 30.025 .. 88 \quad \text{MHz}$$



4. The achieved Protection Ratio, PR_a, for a channel is given by the difference between the received signal strength of the Wanted_Signal, TV transmission, and the received signal strength of the Unwanted_Signal or interfering signal, where both are expressed in dB, dBm or in dBuV/m etc:

$$PR_a = \text{Wanted\_Signal} - \text{Unwanted\_Signal} \qquad \text{dB} \qquad [2]$$

5. Given an achieved protection ratio, PR_a, and a required protection ratio, e.g. Channel(f), for an interference free signal, the excess_noise ratio can be calculated. The excess_noise ratio is the ratio of the received Unwanted_Signal power to the maximum unwanted signal power that can be tolerated and still receive a signal that is interference free and is usually expressed in dB. This is given by:

$$\text{excess\_noise} = \text{Channel}(f) - PR_a \qquad \text{dB} \qquad [3]$$

6. Substituting for PR_a in [3] and rearranging we have:

$$\text{excess\_noise} = \text{Channel}(f) - (\text{Wanted\_Signal} - \text{Unwanted\_Signal}) \qquad \text{dB} \qquad [4]$$

$$excess\_noise = (Channel(f) + Unwanted\_Signal) - Wanted\_Signal \quad dB \quad [5]$$

or

$$excess\_noise = Unwanted\_Signal - (Wanted\_Signal - Channel(f)) \quad dB \quad [6]$$

7. Here we can see that excess_noise expressed in two meaningful ways. In [5] the Unwanted_Signal is multiplied (amplified) by a gain expression equivalent to the required protection ratio and this is compared directly with the Wanted_Signal. In [6] the Unwated_Signal power is compared to what is effectively the system noise floor, (Wanted_Signal - Channel(f)). Conceptually [6] is much closer to reality, but reduces the power levels invloved in calulations by several orders of magnitude, so in this analysis expression [5] is used in preference.

8. Another point to be made from the analysis so far is that the protection ratio is expressed as a function of frequency. This means that when it is combined with the Unwanted_Signal power, the combined terms need to be integrated over the spectrum of interest.

9. Even further examination of the signals involved in the equation is required, however, because if the interfering signal is a Frequency_Hopping signal, then the signal is not time invariant, and there is only a finite probability of the signal appearing at any specific frequency at any given time. Even conceptually, this would suggest that the average power over time on any frequency contained in the set of frequencies over which the radio hops would be less than the peak power emitted at any instant of time. The issue needs to be examined theoretically to provide an understanding of measurement results undertaken, and a proper basis for further decision making.

10. Now noise power is given by:

$$N_p = kTB \cdot watt \quad [7]$$

where:

k = Boltzmann's constant

$k = 1.380 \cdot 10^{-23} \cdot \frac{joule}{K}$

T = temperature in degrees Kelvin

B = bandwidth in Hz

11. Dividing both sides by B gives the noise temperature in joules or in watts/Hz, thus:

$$\frac{N_p}{B} = k \cdot T \cdot \frac{watt}{Hz} \quad [8]$$

12. Examination of the units involved in [7] and [8] reveals that noise temperature, watts/Hz, is the power divided by the bandwidth over which it is distributed. Power is the energy per given period or joule/sec and so can be viewed as the energy per unit period or the average energy over the period.

13. In the case of a hopping radio system, the time period of any averaging, needs to take account of the probability of a frequency being occupied. Since the particular channel visited in a Hop Set is random, the power output on any channel over time is a time average of the peak power. In a random series of Frequency Hops with a finite number of channels, and a long enough time span, each channel is visited an equal number of times, thus the peak power is averaged over the number of channels. Therefore, for a Frequency Hopping radio the average power on any channel is the peak power divided by the number of channels being used in a Hop Set.

14. The average noise power for any RAVEN VHF manpack set, which is hopping over the entire 58 MHz between 30 MHz and 87.975 MHz, ignoring other characteristics such as antennas etc., is given by:

$$N_{Raven} = \frac{5}{58} \quad \text{watt/MHz} \qquad [9]$$

or

$$N_{Raven} = \frac{5}{58 \cdot 10^6} \quad \text{watt/Hz} \qquad [10]$$

15. The CCIR recommendations however specify relative total power at a specified fixed frequency to the power of the TV transmitter taken over the whole of a 7 MHz channel. The recommendations do not specifically take time averaging into account although the recommendation does make an allowance in some way for time averaging by defining different levels for Tropospheric and Continuous interference. This allowance supports the view that an interfering signal should be time averaged even though the TV transmission is not.

16. As indicated previously a specified protection ratio is equivalent to defining the noise floor of the system relative to the received wanted_signal power. A way of analysing this is to treat the protection ratio as gain acting on the interfering signal. The interfering signal and the protection ratio gain then needs to be integrated over the relevant spectrum to calculate the effective noise power of the interfering signal. The effective noise power of the interfering signal can then be used to determine the Excess Noise ratio of the interfering signal in dB.

17. Measurements in Reference B have shown that for an interfering Frequency Hopping radio, hopping only on the 7 MHz of the TV channel, that a protection ratio for the peak interference power, of 42 dB below the a wanted signal level of 50 dBuV/meter, is acceptable. From this information, it is possible to calulate the input power of the TV signal to the reciever, P_{TVdBm}, and the peak power of the Frequency Hopping radio input to the receiver, P_{peak}:

$$P_{TVdBm} = 50 - 120 - 10 \cdot \log(377) + 30 \qquad [11]$$

$$P_{TVdBm} = -65.763 \quad \text{dBm} \qquad [12]$$

and

$$P_{peak} = P_{TVdBm} - 42 \quad \text{dBm} \qquad [13]$$

$$P_{peak} = -107.763 \quad \text{dBm} \qquad [14]$$

18. The average noise power on any 25 kHz channel of a frequency hopping emission when the hop set includes only the Channel 2 band form 63 MHz to 70 MHz is given by:

$$N_{avedBm} = P_{peak} + 10 \cdot \log\left(25 \cdot 10^3\right) - 10 \cdot \log\left(7 \cdot 10^6\right) \qquad [15]$$

$$N_{avedBm} = -132.235 \quad \text{dBm} \qquad [16]$$

$$N_{ave} = 10^{\frac{N_{avedBm}}{10}} \quad \text{mW} \qquad [17]$$

19. The effective noise power of a frequency hopping emission when the hop set includes only the Channel 2 band form 63 MHz to 70 MHz is given by:

$f := 63, 63.025 .. 70$

$$N_{eff} := \sum_{f} 10^{\left(\frac{Channel2(f) + N_{avedBm}}{10}\right)} \qquad N_{eff} = 5.25 \cdot 10^{-7} \quad \text{milliwatts} \qquad [18]$$

$$N_{effdBm} := 10 \cdot \log(N_{eff}) \qquad N_{effdBm} = -62.799 \quad \text{dBm} \qquad [20]$$

$$N_{excess\_ratio} := N_{effdBm} - P_{TVdBm} \qquad [21]$$

$$N_{excess\_ratio} = 2.965 \quad \text{dB} \qquad [22]$$

20. Reference B indicated that a protection ratio of 42 dB was satisfactory for a RAVEN VHF radio frequency hopping on an allocated channel to not cause interference. If the frequency hopping radio is now made to hop over all 2320 channels from 30 MHz to 87.975 MHz i.e. 58 MHz, then the required protection ratio would be expected to be less because the effective noise power on the TV channel would be less:

21. Again assuming that the peak frequency hopping power at the receiver is 42 dB below the a wanted signal level of 50 dBuV/meter we have:

$$P_{TVdBm} := 50 - 120 - 10 \cdot \log(377) - 30 \qquad [23]$$

$$P_{TVdBm} = -65.763 \quad \text{dBm} \qquad [24]$$

and

$$P_{peak} := P_{TVdBm} - 42 \quad \text{dBm} \qquad [25]$$

$$P_{peak} = -107.763 \quad \text{dBm} \qquad [26]$$

$$N_{avedBm} := P_{peak} + 10 \cdot \log\left(25 \cdot 10^{3}\right) - 10 \cdot \log\left(58 \cdot 10^{6}\right) \qquad [27]$$

$$N_{avedBm} = -141.418 \quad \text{dBm} \qquad [28]$$

22. The effective noise power of a frequency hopping emission when the hop set includes the whole 30 to 88 MHz is given by:

$$f := 50.25, 50.275 .. 79.25$$

$$N_{eff} := \left(\sum_{f} 10^{\frac{Channel2(f) + N_{avedBm}}{10}} \right) \qquad N_{eff} = 6.336 \cdot 10^{-8} \quad \text{milliwatts} \quad [29]$$

$$N_{effdBm} := 10 \cdot \log(N_{eff}) \qquad N_{effdBm} = -71.982 \quad \text{dBm} \quad [30]$$

$$N_{excess\_ratio} := N_{effdBm} - P_{TVdBm} \quad [31]$$

$$N_{excess\_ratio} = -6.218 \quad \text{dB} \quad [32]$$

23. This is a reduction in effective noise power or interference of:

$$Reduction := 2.965 \quad 6.218 \quad [33]$$

$$Reduction = 9.183 \quad \text{dB} \quad [34]$$

24. The measurements performed in Reference B indicate a reduction of 6 dB could be allowed in the protection ratio.

25. Similarly it would be expected, given the CCIR protection curves, that not allowing the radio to hop on any frequency in the TV channel would cause a significant reduction in the required protection ratio. If the frequency hopping radio is now made to hop over all 2320 channels from 30 MHz to 87.975 MHz barr Channel 2 frequencies from 63 to 70 MHz i.e. 51 MHz, then:

26. Again assuming that the peak RAVEN power at the receiver is 42 dB below the a wanted signal level of 50 dBuV/meter we have:

$$P_{TVdBm} := 50 - 120 - 10 \cdot \log(377) + 30 \quad [27]$$

$$P_{TVdBm} = -65.763 \quad \text{dBm} \quad [28]$$

and

$$P_{peak} := P_{TVdBm} - 42 \quad \text{dBm} \quad [29]$$

$$P_{peak} = -107.763 \quad \text{dBm} \quad [30]$$

$$N_{avedBm} := P_{peak} + 10 \cdot \log(25 \cdot 10^{3}) - 10 \cdot \log(51 \cdot 10^{6}) \quad [31]$$

$$N_{avedBm} = -140.86 \quad \text{dBm} \quad [32]$$

27. The effective noise power of a frequency hopping emission when the hop set excludes the Channel 2 band form 63 MHz to 70 MHz is given by:

$f := 50.25, 50.275 .. 79.25$

$$N_{whole\_band} := \left(\sum_f 10^{\frac{Channel2(f) + N_{avedBm}}{10}} \right) \qquad N_{whole\_band} = 7.206 \cdot 10^{-8} \qquad [33]$$

$f := 63, 63.025 .. 70$

$$N_{barr} := \left(\sum_f 10^{\frac{Channel2(f) + N_{avedBm}}{10}} \right) \qquad N_{barr} = 7.206 \cdot 10^{-8} \qquad [34]$$

$$N_{eff} := N_{whole\_band} - N_{barr} \qquad N_{eff} = 5.472 \cdot 10^{-12} \qquad [35]$$

$$N_{effdBm} := 10 \cdot \log(N_{eff}) \qquad N_{effdBm} = -112.619 \quad \text{dBm} \qquad [36]$$

$$N_{excess\_ratio} := N_{effdBm} - P_{TVdBm} \qquad [37]$$

$$N_{excess\_ratio} = -46.855 \quad \text{dB} \qquad [38]$$

28. This is a reduction in effective noise power or interference of:

$$Reduction := 2.965 - -40.855 \qquad [39]$$

$$Reduction = 43.82 \quad \text{dB} \qquad [40]$$

29. The measurements performed in Reference B indicate a reduction of 42 dB to 45 dB could be allowed depending on the television receiver.

30. The effective noise power of a frequency hopping emission when the hop set excludes the Channel 2 band +/- 3.5 MHz from 59.5 MHz to 73.5 MHz is given by:

$f := 50.25, 50.275 .. 79.25$

$$N_{whole\_band} := \left(\sum_f 10^{\frac{Channel2(f) + N_{avedBm}}{10}} \right) \qquad N_{whole\_band} = 7.206 \cdot 10^{-8} \qquad [41]$$

$f := 59.25, 59.275 .. 73.5$

$$N_{barr} := \left(\sum_f 10^{\frac{Channel2(f) + N_{avedBm}}{10}} \right) \qquad N_{barr} = 7.206 \cdot 10^{-8} \qquad [42]$$

$$N_{eff} = N_{whole\_band} - N_{barr} \qquad N_{eff} = 2.197 \cdot 10^{-13} \qquad [43]$$

$$N_{effdBm} = 10 \cdot \log(N_{eff}) \qquad N_{effdBm} = -126.582 \quad \text{dBm} \qquad [44]$$

$$N_{excess\_ratio} = N_{effdBm} - P_{TVdBm} \qquad [45]$$

$$N_{excess\_ratio} = -60.818 \quad \text{dB} \qquad [46]$$

31. This is a reduction in effective noise power or interference of:

$$Reduction = 2.965 - -60.818 \qquad [47]$$

$$Reduction = 63.783 \quad \text{dB} \qquad [48]$$

32. The measurements performed in Reference B indicate a reduction of 54 dB to 62 dB could be allowed depending on the television receiver.

33. The effective noise power of a frequency hopping emission when the hop set excludes the most sensitive parts of the Channel 2 band from 63-65 MHz and 68-69 MHz is given by:

$$f = 50.25, 50.275 .. 79.25$$

$$N_{whole\_band} = \sum_{f} 10^{\frac{Channel2(f) - N_{avedBm}}{10}} \qquad N_{whole\_band} = 7.206 \cdot 10^{-8} \qquad [49]$$

$$f = 63.0, 63.025 .. 65.0$$

$$N_{barr} = \sum_{f} 10^{\frac{Channel2(f) + N_{avedBm}}{10}} \qquad N_{barr} = 2.767 \cdot 10^{-8} \qquad [50]$$

$$f = 68.0, 68.025 .. 69.0$$

$$N_{barr} = N_{barr} + \sum_{f} 10^{\frac{Channel2(f) - N_{avedBm}}{10}} \qquad N_{barr} = 3.831 \cdot 10^{-8} \qquad [51]$$

$$N_{eff} = N_{whole\_band} - N_{barr} \qquad N_{eff} = 3.375 \cdot 10^{8} \qquad [52]$$

$$N_{effdBm} = 10 \cdot \log(N_{eff}) \qquad N_{effdBm} = -74.717 \quad \text{dBm} \qquad [53]$$

$$N_{excess\_ratio} = N_{effdBm} - P_{TVdBm} \qquad [54]$$

$$N_{excess\_ratio} = -8.954 \quad \text{dB} \qquad [55]$$

34. This is a reduction in effective noise power or interference of:

$$\text{Reduction} = 2.965 - -8.954 \qquad [56]$$

$$\text{Reduction} = 11.919 \quad \text{dB} \qquad [57]$$

35. The measurements performed in Reference B indicate a reduction of 6 dB could be allowed depending on the television receiver.

Title: **CCIR Protection Ratios for USA NTSC Television Channels sharing with Fixed and Mobile stations causing continuous or equivalent interference in the 30 to 88 MHz band.**

Issue: 1

Author: Graeme G. Glenn

References:

A. CCIR Recommendation ITU-R IS851-1, Sharing between the Broadcasting Service and the Fixed and/or Mobile Services in the VHF and UHF Bands.

Purpose: To detail the protection ratios required by CCIR Recommendation ITU-R IS851-1 for continuous type interference for USA NTSC Television Channels.

Discussion:

1 USA NTSC Television Channels have the following characteristics:

Modulation Type	Vestigial Sideband NTSC
Channel Bandwidth	6 MHz
Vision Carrier	1.25 MHz above lower edge of channel negative amplitude modulation
Field Frequency	59.94 Hz
Frame Frequency	29.97 Hz
Fields per Frame	2
Lines per frame	525 lines (interlaced 2:1)
Line Frequency	15734.3 Hz
Colour Sub-Carrier	3.57955 MHz
Sound Main Carrier	4.5 MHz above vision carrier

2 CCIR Rec. ITU-R IS.851-1 requirements for Continuous and Troposheric Protection for the NTSC system are given in the table below:

Relative[1] Frequency MHz	Protection Ratio Interference Type Cont. dB	Trop. dB	Cont. Int. Straight Line Approximation[2 & 3] m	c
-7.25	-26	-36	-	-
-5.25	-15	-25	5.5	13.875
-3.5	10	0	14.2857	60
-2.25	3	-7	-5.6	-9.6
-1.5	10	0	9.33333	24
-1	40	30	60	100
-0.75	50	40	40	80
0.3	60	50	9.52381	57.1429
1	60	50	0	60
2.5	47	37	-8.6667	68.6667
3	55	45	16	7
3.5	60	50	10	25
3.7	60	50	0	60
4.1	55	45	-12.5	106.25
4.5	25	15	-75	362.5
4.75	16	6	-36	187
5.75	5	-5	-11	68.25
6.75	-9	-19	-14	85.5
8.75	-22	-32	-6.5	34.875
10.75	-30	-40	-4	13

Table 1 Protection Ratio - Continuous & Tropospheric Conditions

Note[1]

Frequency relative to the nominal carrier frequency which is 1.25 MHz above the bottom of the bottom band edge.

Note[2]

The straight line approximation is of the form $PR_{dB}=m*fr+c$ and applies for the frequency of the current line and all frequencies down to and including the frequency of the line above.

e.g. $PR_{dB}=m*fr+c$

for $-7.25 \le fr \le -5.25$

m = 5.5 and c = 77.25

PRdB= -26 @ -7.25 MHz

PRdB= -15 @ -5.25 MHz

Note[3]

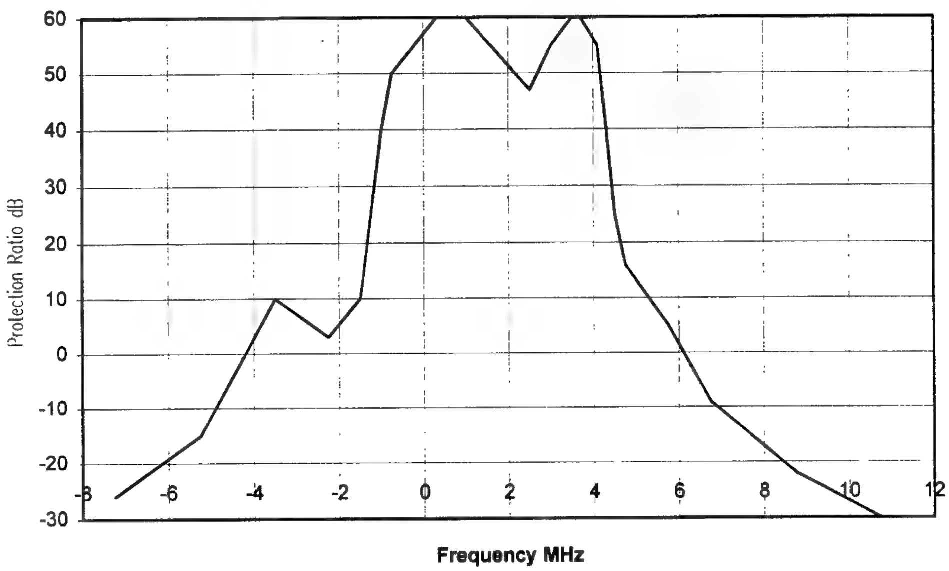
The straight line approximation may be extended for Tropospheric propagation by subtracting 10 dB from the value for c.

Title:	**CCIR Protection Ratios for USA NTSC Television Channels sharing with Fixed and Mobile stations causing continuous or equivalent interference in the 30 to 88 MHz band.**	**Issue:** 1 **Author:** Graeme G. Glenn

Discussion cont:

3 For USA NTSC Television channels the Protection Ratio is graphed in relationship to the vision carrier nominal frequency which is 1.25 MHz above the bottom of the channel.

Figure 1 Protection Ratio for USA NTSC TV Channels



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Discussion cont:

4 Relating the data to the bottom edge of the channel produces Table 2

Relative[1] Frequency MHz	Protection Ratio Interference Type Cont. dB	Trop. dB	Cont. Int. Straight Line Approximation[2 & 3] m	c
-6	-26	-36	-	-
-4	-15	-25	5.5	7
-2.25	10	0	14.2857	42.1429
-1	3	-7	-5.6	-2.6
-0.25	10	0	9.33333	12.3333
0.25	40	30	60	25
0.5	50	40	40	30
1.55	60	50	9.52381	45.2381
2.25	60	50	0	60
3.75	47	37	-8.6667	79.5
4.25	55	45	16	-13
4.75	60	50	10	12.5
4.95	60	50	0	60
5.35	55	45	-12.5	121.875
5.75	25	15	-75	456.25
6	16	6	-36	232
7	5	-5	-11	82
8	-9	-19	-14	103
10	-22	-32	-6.5	43
12	-30	-40	-4	18

Table 2 Protection Ratio USA Television[1]

Note[1]

Frequency relative to the bottom edge of the Television Channel.

Note[2]

The straight line approximation is of the form $PR_{dB}=m*fr+c$ and applies for the frequency of the current line and all frequencies down to and including the frequency of the line above.

e.g. $PR_{dB}=m*fr+c$

for $-6.0 \le fr \le -4.0$

m = 5.5 and c = 7

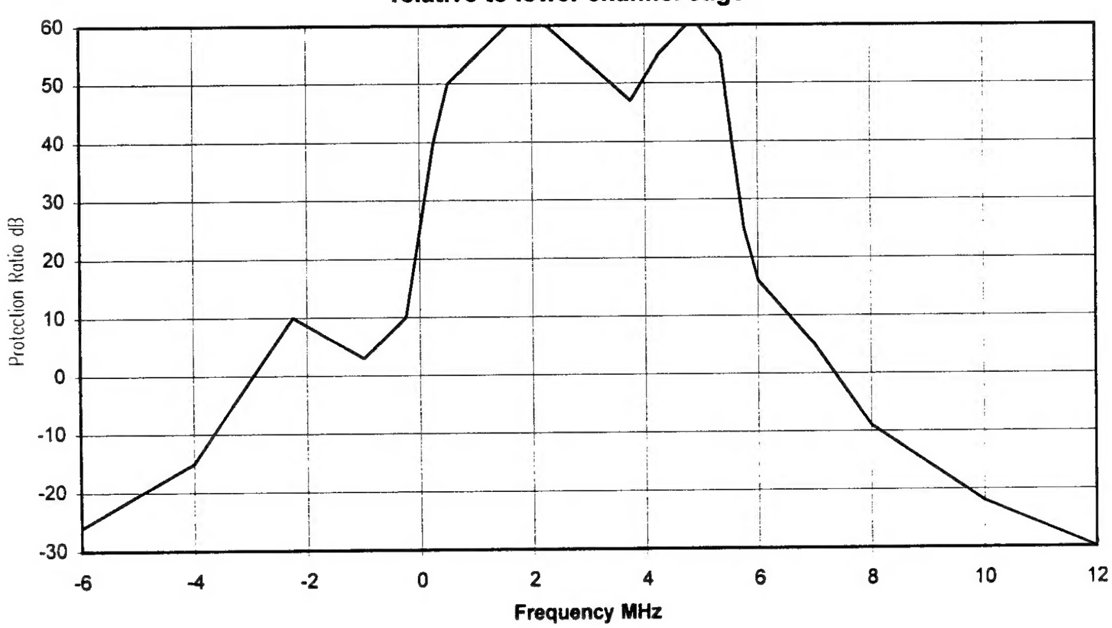
PRdB= -26 @ -6 MHz

PRdB= -15 @ -4 MHz

Note[3]

The straight line approximation may be extended for Tropospheric propagation by subtracting 10 dB from the value for c.

Figure 2 Protection Ratio - USA NTSC Television relative to lower channel edge



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SHARING BETWEEN THE BROADCAST SERVICE AND VHF RADIO RT-F200 IN FREQUENCY HOPPING MODE

by
Graeme G. Glenn
Communications Engineering Unit

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16. ABSTRACT

Several reports on interference caused by Frequency Hopping radios are reviewed. A theoretical model based on ITU-R IS.851-1 is developed and validated against data obtained from measurements made at Department of Communications and the Arts Laboratories. Parameters for various antenna configurations used in the Australian Army are then given and coupled with pathloss predictions to estimate required distance separations for full band frequency hopping radios from Primary Service areas of Television Broadcast transmitters.